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16. ABSTRACT

The accumulative effects of annual use of sewage sludge on composition of soils, plants, water, and animals that consume the plants is presented. Plant yields were increased and no evidence of phytotoxicity from trace elements was observed. Phosphorus toxicity in soybeans developed. No adverse health effects were observed in pheasants or swine that were fed grain from sludge-treated plots.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The ability to make objective decisions about waste utilization or disposal is often limited by the information available. This report describes an attempt to examine the effects of various management practices followed in land application of sludge and to determine the optimum rate of application and the best management schemes to minimize adverse environmental effects and achieve the most benefit from agricultural use of sludge.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

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EFFECTS OF USING SEWAGE SLUDGE ON AGRICULTURAL AND DISTURBED LANDS

by

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Grant No. S801356

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ABSTRACT

Digested sewage sludge was annually applied for eight years on field lysimeter plots at rates up to more than four times the amount needed to supply supplemental N for optimum corn yields. Concentrations of NH_4-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, total solids, organic-C and electrical conductivities of runoff and drainage waters from these plots were frequently higher than those of similar samples from control plots. Concentrations of NO_3-N were markedly increased in drainage water and, to a lesser extent, in runoff water. Soil concentrations of several chemical elements also increased but the only phytotoxic condition produced by excessive sludge loading rates applied each year was P-toxicity in soybeans. Effects of P-toxicity were evident only during the first year after sludge applications were terminated. Concentrations of metals in corn and soybean tissues and especially in corn grain decreased rapidly following the termination of sludge applications. Uptake of metals by corn grown on three soil types with very different cation-exchange capacities was about the same from plots which had received similar sludge treatments.

Testing inbred corn lines and their progeny demonstrated that the capacity to exclude Cd from the aerial parts of plants is an inherited character which suggests that metal uptake could be controlled through plant breeding. Results from analyzing fractions obtained from dry-milling corn grain and wheat showed that major portions of Cd and other inorganic elements were contained in those fractions that are used as animal feedstuffs.

Applying sludge each year for 10 years on continuous corn plots improved soil physical properties and never adversely affected seed germination. Organic matter in sludge is mineralized within a few months after incorporation into soils and an equilibrium between amounts added and amounts lost each year is approached in three to four years. Sludge applications to soil appeared to have no deleterious effect on soil microbial populations and enzyme activity.

No adverse health and performance effects were ever observed in pheasants, rats and swine fed rations composed of grains containing the highest concentrations of biologically incorporated Cd possible to obtain by irrigating continuous corn and soybean plots with digested sewage sludge.

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SECTION 1

INTRODUCTION

Digested sewage sludge is an effective source of both nitrogen and phosphorus for the fertilization of growing crops. When sludge is applied by ridge and furrow irragation, crop yields are comparable or greater than those obtained with inorganic fertilizers applied at rates estimated to be adequate for maximum yields. This use of sludge is the most environmentally safe and economically sound solution to the growing solids waste handling problem. All other methods of sludge disposal pose a direct or potential air and/or water pollution hazard. When sludges from municipal wastewater treatment plants are burned, buried in land fills or dumped into oceans, control over the dispersion of chemical constituents into the environment is relinquished to a very marked degree.

Still, resistance to land spreading of digested sludges arises with regard to its trace element content. There is concern over the potential threat of these metals to human health. Many studies have demonstrated the toxic effects of cadmium when the metal is ingested or injected as a soluble Cd salt. These investigations, though interesting in their own right, tell us very little about the flow of Cd through the food-chain when its origin is sewage sludge.

When sludge is used at agronomically appropriate rates, our previous report (Hinesly et. al. 1974) indicates that the risks of adverse health effects toward humans or livestock are minimal. However, we recognized that when digested sludge is used as a soil amendment at rates which greatly exceed those needed to optimize fertility, the possibility does exist that trace elements such as Zn, Cu, Cd, and Ni may be absorbed and transported into plant tissues in amounts which may be harmful to animals. We herein report our continued investigations to assess these potential dangers through additional feeding studies and long-term monitoring of the agro-ecosystem.

SECTION 2

CONCLUSIONS

Results obtained from field lysimeter studies initiated in 1969 showed that when digested sewage sludge was annually applied for 8 years at rates more than four times greater than needed to supply supplemental N for optimum corn yields, the concentration of NO_3-N was markedly increased in soil drainage water, and, to a smaller extent, in runoff water. At these excessive sludge loading rates, concentrations of NH_4-N, P, K, Na, Zn, Cu, Ni, Cd, Cr, total solids, organic-C, and electrical conductivities of runoff and drainage waters were frequently higher than in similar samples from control plots. Concentrations of Pb, Se, As, Sb, and Hg were not enhanced by the excessive sludge loading rates. Iron and Mn concentrations in drainage waters from the finer-textured soils were often decreased by maximum sludge applications and were unaffected in runoff water. Only NO_3-N levels in drainage water and Cd concentrations in both runoff and drainage water frequently exceeded recommended limits permitted in public water supplies. Where sludge application rates were one-fourth those applied on maximum-sludge-treated plots, geometric mean NO_3-N concentrations in drainage waters were not different from those in drainage waters from control plots treated with inorganic N fertilizers at rates calculated to be adequate for maximum corn grain yields. Concentrations of NO_3-N in drainage water fluctuated between high and low values during any particular flow event. This result demonstrates the impossibility of trying to assess the potential or actual loss of N based on analytical results obtained from a few grab samples collected from field tiles. Even though about 35% to 45% of the total N contained in sludge was in the NH_4-N form, very little reached the drainage tile in this form. During periods when weather conditions were favorable for rapid dewatering of sludge on the soil surface, large quantities (40%) of NH_4-N were lost by volatilization, but very little was lost when sludge was applied during cool, rainy periods. Nevertheless, nitrification processes were always sufficient to maintain NH_4-N concentrations in drainage waters at very low levels, regardless of soil type.

Geometric mean Cd concentrations were increased in drainage water by maximum sludge applications. But where sludge loading rates were comparable to those recommended on the basis of protecting ground water against unacceptable levels of NO_3-N, Cd concentrations were about the same as found in drainage waters from control plots. Concentrations of Cd in drainage water from control plots frequently exceeded recommended maximum levels in public water supplies. Metal concentrations in runoff water from lysimeter plots were probably higher than would have been found in streams receiving waters from large fields treated with the same sludge, at equivalent loading rates and protected against excessive erosion. Runoff water samples were collected directly from the lower end of lysimeter plots preventing sedimentation of suspended particulates and scavenging of heavy metals by overland flow processes that would occur under field conditions. Comparisons of 1976-1977 results with those obtained in earlier years showed that water quality had not been significantly changed by increased years of applying sludge at maximum loading rates. Thus the soil's capacity to retain and/or attenuate concentrations of contaminant in water was not reduced during the 6 years by annual sludge application, regardless of soil type or loading rate. Conclusions drawn from the water chemistry data are that if sludge were applied at rates just adequate to supply N for nonleguminous plants on land areas adequately protected against excessive erosion, changes in runoff and drainage water quality from that produced by more conventional fertilizer practices would be negligible.

In comparison to densities in waters from control plots, numbers of fecal coliform organisms were fewer than expected from sludge-amended soil, considering that when applied, the sludge generally contained 10^5 to 10^7 organisms/100 ml. Fecal coliform densities were higher in both drainage and runoff water during the fall and early winter season than at any other time during the year. During this period, about 50% of the drainage water samples from control plots contained greater than 10 organisms/100 ml as contrasted to greater than 25 fecal coliform/100 ml in drainage water from maximum-sludge-treated plots. A greater proportion of the runoff water samples contained higher densities of fecal coliform than was found in drainage water, but relative differences between samples from control and maximum-sludge-treated plots remained about the same. There was no indication that fecal coliform densities were increased in either runoff or drainage waters by increased years of applying sludge. Because fecal coliforms are always present in soil and survive for longer periods of time than enteric pathogens, it may be concluded that careful use of digested sludge will result in only a low density of pathogens in runoff or drainage water.

Results from long-term studies initiated in 1968 and 1969 showed that annual sludge applications had caused increases in soil concentrations of several chemical elements, some of which are not known to be essential for plant growth. In general, only the chemical and physical properties of the surface horizons (0-30 cm) of soils were affected by sludge application. Corn, soybeans, and wheat accumulated several inorganic sludge constituents to relatively high levels in foliage and grain tissues. But none of the inorganic elements were accumulated by plants at levels above an expected upper range in normal plants except for P, Zn, Cd, and Ni. At recommended sludge loading rates, none of these elements except Cd exceeded normal expected levels in plant parts. At excessive sludge loading rates, only P caused a phytotoxic condition in soybeans. The P phytotoxicity did not persist. One year after sludge applications were terminated, soybean yields were higher on maximum-sludge-treated than on control plots. Concentrations of metals in corn and soybean tissues also decreased after sludge applications were terminated. Four years after terminating sludge applications on plots planted to corn, grain-metal concentrations were not different between control and maximum-sludge-treated plots. Yields were significantly increased as a result of residual effects of sludge applications during the third and fourth year after applications were terminated. On another series of continuous corn plots where sludge applications were made each year for 10 years, maximum loading rates (about 50 mt/ha dry weight annually) never decreased corn yields. In several of the years, maximum sludge applications increased corn yields over those obtained from highly fertilized control plots. Within the framework of the chemical properties of the sludge used in these studies, it is concluded that it can be used at recommended agronomic rates without fear of developing phytotoxic conditions either during or after termination of annual sludge applications. Even though total concentrations of several elements increased significantly in soils each year as a result of annual sludge applications, concentrations of plant available elements increased only slightly. After the first year or two of annual sludge applications the uptake of nutrient and non-nutrient elements by a partiuclar plant species remains fairly constant when year to year and batch to batch variations in the chemical composition of sludge and loading rates are considered. Cation-exchange capacity of soils does not affect plant uptake of metals from sludge-amended soil, as evident from the fact that uptake by corn was about the same from similarly treated Blount silt loam, Elliott silt loam and Plainfield loamy sand soils.

Rather extensive studies conducted on soil samples from field plots showed that total bacteria counts and populations of actinomycetes were increased by sludge applications, along with increased activities of catalase, xylanase, amylase, cellulase, invertase, and protease. Bacterial spore counts and azotobacter populations were decreased, while fungi populations and urease activity were unaffected by sludge applications. From laboratory studies it was found that the types of microorganisms colonizing corn plant residues in sludge-amended soil at a particular time were in accord with the expected classical succession. Therefore, it is concluded that annual sludge applications have not restricted microbial populations or their activities.

On a dry weight basis organic-C ranges from 20 to 30 percent and organic-N from 2.5 to 4% in digested sewage sludge. About 50 to 60% of the organic matter in sludge is mineralized within a few months after incorporation in soils. Thus, soil organic-C contents approach an equilibrium between amounts annually added as a constituent of sludge and amounts lost by mineralization processes in about 3 to 4 years. While nearly every major soil organic matter fraction was increased by sludge applications, the greatest increase occurred in the fraction containing fats, waxes, and oils. About 15 to 30% of the total organic-C of sludges is contained in the fats, waxes and oils fraction. Only about 35% of these compounds are mineralized during the year they are added to soils as constituents of sludge. But it appears that after about 6 years an equilibrium condition is established between annual additions of fats, waxes, and oils and their loss from soil by mineralization processes. Applying sludge each year for 10 years on continuous corn plots has improved soil physical properties and has never adversely affected seed germination. Because of improved physical condition, it is likely that the organic matter contained in digested sewage sludge will increase the productivity of many low organic matter soils.

Although not completely elucidated, results from testing inbred corn lines and their progeny suggest that the capacity to exclude Cd from above ground parts of plants is an inherited characteristic. It is concluded that if the accumulation of Cd and other metals in cereal grains presents a health hazard to man or animals, it can be maintained at acceptable levels by plant breeding techniques.

Results from analyzing fractions obtained from dry-milling corn grain and wheat showed that major portions of Cd and other inorganic elements were contained in those fractions that are used as animal feed-stuffs and only minor portions remain in the food-stuff. Considering the nominal increases in concentrations of Cd and other inorganic elements observed in cereal grains when sludge was applied at agronomic rates, the small land area that would ever be treated with sludge, the unavoidable mixing of grain from different farms at elevators and during transportation, and the concentration reduction in the fractions of cereal grain kernels used for direct human consumption that occurs during dry-milling, the use of sewage sludge to fertilize grain crops would not cause a measurable increase of metals in the cereal fraction of human diets.

No adverse health and performance effects were ever observed in pheasants, rats, and swine fed rations composed of grains containing the highest concentrations of biologically incorporated Cd possible to obtain with the sludges used to irrigate continuous corn and soybean plots. For a "worst case" situation, swine were overwintered on control plots and plots annually irrigated with sludge for 8 years. Sows foraging on plots amended with amounts of sludge considered to be appropriate agronomic rates for corn frequently outperformed those on control and maximum-sludge-treated plots. This pattern persisted for weight gain, in-utero piglet survival, blood hemoglobin, and tissue Fe concentrations, even though the diet fed all swine was standard and nutritionally adequate. Some relatively low but statistically significant increases of Cd concentrations were found in the livers and kidneys of animals consuming rations having higher Cd levels, but no increases were ever observed in muscle tissue. Concentrations of Cd were increased in the spleen, pancreas, liver, and kidneys of sows foraging on plots treated with sludge at rates four times higher than recommended rates, but concentrations in muscle tissue were not increased. It is concluded that sludges used in these studies, applied at agronomic rates, would not present a health hazard to animals consuming grain produced on sludge-amended soils nor would their performance or health be impaired by foraging on crop residues in sludge-treated fields. Since visceral organs constitute only a minor proportion of the total human diet, it seems unlikely that the use of sludge as a fertilizer would present a public health hazard through food-chains that include animals.

SECTION 3

RECOMMENDATIONS

The findings presented in this report prompt the following recommendations:

1. Considering the cost and public health hazards associated with all other methods of disposal, the utilization of municipal sewage sludge as a supplementary N and P fertilizer or as an amendment for the reclamation of severely disturbed lands should be established as a high priority alternative.

2. Only sludges that have been well stabilized should be spread on land.

3. To reduce pathogens sludges should be stored for at least 3 months after digestion unless they are immediately incorporated into the soil.

4. On productive agricultural lands, loading rates should be adjusted to the requirements of nonleguminous crops for N and the capacity of leguminous crops to utilize N. When sludge is used as a soil amendment to reclaim severely disturbed land, where slowly permeable geological materials protect ground water against contamination by excessive leaching of NO_3-N from the surface, loading rates should be determined by the operator's ability to control excessive erosion and produce an acceptable runoff water quality.

5. Time of sludge applications should be made according to soil type to insure maximum utilization of N by crops. For instance, on very permeable, sandy soils, it may be necessary to apply increments of the total annual sludge loading rate at appropriate intervals during the growing season.

6. There is no evidence that stabilized sludges from biological wastewater treatment plants have reduced the productivity of soils when applied at agronomic rates. Where sludge was applied annually for several years, crop yields were increased during years when rainfall was below optimum amounts.

7. Priority should be given to reducing Cd concentrations in wastewater, even though there is no evidence that concentrations in stabilized sludges from biological wastewater treatment plants have affected the productivity of soils or the health of animals consuming the produce. It is perceived to be a problem by many environmentalists and public

health officals because Cd is not presently known to be essential for either plants or animals. Enhanced levels of Cd in plant tissues are reflected in the livers and kidney of animals. Therefore, prudence dictates that an effort be made to reduce concentrations to the lowest levels practicable.

8. Except for Cd, the other metals whose concentrations increase in plant tissues as a result of sludge applications are either essential for plants or animals or both. Thus, these should not be referred to as toxic elements. Many of these are added to rations to improve animal performance. Often concentrations in rations are higher than could be obtained in plant tissues by using sludge as a fertilizer for standard varieties of field crops.

9. For a specific annual sludge loading rate on soils, where Cd concentrations in sludges are notsubstantially changed, accumulative applications of sludge are of little importance with regard to determining Cd concentrations in plant tissues after the second and third year of annual applications. However, accumulative sludge-borne Cd applications on calcareous strip-mine spoil may cause increased concentrations in plants.

10. Where water supplies can be protected against contamination with NO_3-N, it will often be beneficial to apply sludge in amounts that exceed agronomic loading rates to take advantage of its organic matter content to restore disturbed and improved marginal farm lands to as high a level of productivity as possible.

11. For those who perceive enhanced levels of metals in tissues of healthy plants as a potential public health hazard, maximum permissible levels in plant produce should be established. It is well known that there is little relationship between total metal contents of soils and amounts accumulated from it by plants. Metal concentrations in plant tissues vary to a greater extent between plant species and even varieties within a particular species than are observed when the same variety is grown on soils with different total concentrations of metals. Soils will not be irreparably damaged by additions of sludge-borne metals, because their availability for uptake by plants will decrease with time after sludge applications are terminated. During the time that sludge is utilized, varieties of plants can be selected to maintain metals at acceptable levels in the produce. Regulations should be promulgated on the basis of produce quality rather than on management practices.

SECTION 4

FIELD LYSIMETER STUDIES

GENERAL DESCRIPTION

Beginning in 1969, sludge from high-rate anaerobic digesters at the Calumet and Stickney wastewater treatment plants near Chicago was applied by irrigation on 44 lysimeter plots measuring 3.05 by 15.25 m. Plots were arranged in two banks of 22 plots each, referred to below as north and south series. The lysimeter installation was located on a small watershed on the Northeast Agronomy Research Center near Elwood, Illinois. Each sludge treatment was replicated three times on the native Blount silt loam soil occupying the small watershed. Elliott silt loam soil was simulated in 10 lysimeters by removing the surface one-foot depth of Blount silt loam and replacing it with an equivalent depth of surface soil from Elliott silt loam sites. Also, 10 lysimeter plots were constructed by excavating the complete plot to a depth of 1.52 m and filling with Plainfield sand. Tile drains were installed through the center of each lysimeter plot and a fiberglass trough was installed at the downslope end of each plot to collect runoff water. Both drainage water and runoff water were conveyed separately through PVC pipes from the plots by gravity to the basement of an instrument house. Tipping bucket equipment was provided to measure rates and total volume of flows from each of the PVC pipes through which either runoff or drainage water was delivered from the plots to the instrument house basement. Automated sampling equipment was provided for each of the PVC pipes and, for the most part, a 400 ml sample was collected from the second tip of a tipping bucket and again on each sequential 42nd tip of a bucket thereafter for the duration of a flow event. Thus, except for some special studies, a sample represented the instantaneous water flow that occurred between each 42 volumes of sequential flow. The equipment was designed to take samples at more frequent volumes of flow if desired, but the number of water samples collected at the selected flow volume increments were all that could be conveniently analyzed for heavy metals and several other parameters. Multiple-channel event recorders were used to record rates and total flow volume of runoff and drainage waters relative to clock time. Detailed descriptions of all the flow volume measuring, recording, and sampling equipment, as well as the construction of lysimeter plots were presented in an earlier report (Hinesly et al., 1974) and therefore are not discussed in detail here. After the original recording and control equipment was destroyed by fire in January, 1975, a mini-computer was installed to control the sampling equipment and record flow data. Usually only one composite water sample representing a single flow event from a particular control or maximum-sludge-treated plot of Blount or Elliott silt loam was collected after 1975. These two soil types were located, respectively, on the south and north sides of the instrument house.

During the first 2 years, the plots were tilled with a field cultivator and disked prior to planting soybeans (Glycine max L.) on the north and corn (Zea mays) on the south series of plots. The seedbed was prepared in the same way during the third year when corn was planted on both series. In the spring of succeeding years, the plots were thoroughly mixed to a depth of about 15 cm with a rotary plow. During the first 3 years anaerobically digested sludges (3 to 4% solids in suspension) from the Southwest and Calumet wastewater treatment plants in Chicago were applied during the growing season with a sprinkler irrigation system. The maximum amount of sludge that could be applied each time by sprinkler irrigation was a surface layer of about 12.7 mm. To avoid frequent, light applications, a ridge and furrow system was used to apply sludge during subsequent years. Liquid sludge was applied in furrows at rates equivalent to total surface depths of 6.4, 12.7, and 25.4 mm to achieve three different loading rates. Additional sludge, at appropriate rates, was applied during the growing season when the level of sludge in the maximum-treated plots had been sufficiently lowered by infiltration and evaporation to hold another application. Plots receiving lesser amounts were treated from the same load of sludge used for maximum-treated plots and applied on the same day. Control plots were irrigated with 25.4 mm of well water on the same day sludge applications were made. All plots were fertilized with KCl to supply 134 kg K/ha prior to the preparation of seedbeds. Control (zero liquid sludge) plots received fertilizer applications of 268 kg N/ha and 134 kg P/ha as NH_4NO_3 and superphosphate. Fertilizer, liquid sludge and water applications were terminated on all Blount silt loam plots in the north series at the end of the 1973 growing season. Applications of sludge, at rates less than the maximum, were also discontinued on Elliott silt loam and Plainfield loamy sand plots in the north series. But sludge applications were continued on all plots in the south series until the end of the 1976 growing season. After 1976, sludge was applied only on Blount silt loam plots in the south series.

METHODS OF COLLECTING AND ANALYZING SAMPLES

As water samples were removed from automated sample collection equipment they were sealed with a clean cap, labeled to identify the date, plot number, kind of water (runoff or drainage) and sequence of sampling, after which they were placed in specially prepared shipping crates for transfer to the laboratories within a period of 30 hours after collection. Upon receipt at the laboratory, 10 to 100 ml of representative water samples from each sample was withdrawn for fecal coliform analyses. The amount used for fecal coliform determinations varied with the suspended solids or colloid content of the water samples. Some samples, especially runoff water samples, contained suspended solids contents high enough to present difficulty in filtering. Fecal coliform counts were made by the membrane filter procedure as described by Taras et al. (1971). Nitrate nitrogen concentrations were determined within a week of the sample collection data by the use of a Corning specific ion electrode. Ammonium nitrogen concentrations were determined in aliquot water samples, which were acidified immediately after receipt, by use of an Orion gas sensing electrode. Using a standard conductivity bridge procedure, conductivity determinations were made within one week after collection. Within 1 to 2 days after the water samples were collected, pH values were determined by the use of a combination (reference and hydrogen ion) electrode. Total solids were determined by evaporating the water (50 to 60 g) and drying at 110°C. Percent solids were then calculated from the weight of remaining dry residues. All of the elements Zn, Cu, Cd, Ni, Cr, Pb, Fe, and Mn were determined from a water sample volume of 150 ml to which 2 ml of 6 N HCl (redistilled) was added before evaporating to dryness on a steam heated sand bath, whereupon an additional 2 ml of 6 N HCl was added to samples before evaporating to dryness for a second time. To the dry residues, 10 ml of 1.0 N HCl (redistilled) was added and refluxed with a watch glass cover for one hour (on a sand bath). Samples were then diluted to 25 ml with deionized water, filtered and analyzed by atomic absorption spectroscopy. The same procedure was used in the preparation of water samples for determination of K and Na concentrations, but for these two elements emission spectroscopy was employed for analyses. Water samples, concentrated to 5 to 10 ml by evaporation on a warm sand bath before and again after 1.0 N HCl and 30% H_2O_2 were added were diluted to 25 ml for spectrographically determining concentration of Se, As, and Sb by generation of their hydrides in an air entrained hydrogen flame and Hg by the cold vapor technique (Hwang et al., 1971). Organic-carbon concentrations were determined without concentrating water samples by employing a commercial organic carbon analyser. Aliquots were withdrawn soon after the water samples were delivered to the laboratory, but most of the determinations for total P concentrations were scheduled as dictated by convenience. Determination of P concentrations were made by the molybdate blue method as described in FWPCA Methods for Chemical Analysis of Water and Waste (U.S. Dept. of Interior, 1969, Pg. 223).

Prior to 1973, after plowing the plots, surface soil samples (0-15 cm) were collected with a spade each spring and a soil auger was used to take subsoil samples (30-46 cm). After 1972, six soil cores to a depth of 76 cm were taken from each plot, using stainless steel tubes. Soil cores were segmented and composited to provide representative samples of the 0 to 15, 15 to 30, 30 to 46, and 61 to 76 cm soil depths. After drying (60°C), crushing, and pulverizing (60-mesh screen) soil samples (0.5 g) were heated to 500°C for 24 h, digested in concentrated HCl-HF, and dissolved in N HCl for total heavy metal analyses by atomic absorption spectrophotometry (Hinesly et al., 1977). As an estimate of availability for uptake of metals by plants, 1 g of soil from all sampled depths was extracted with 20 ml of 0.1 N HCl, through 1974. Soil pH was determined in one-to-one soil to water paste.

Sludge samples, collected at the beginning and end of each irrigation event, were prepared and analyzed in a manner similar to that for soil after they were dried (110°C) to a constant weight, except they were not digested with HCl-HF. Total organic carbon concentrations in soil and sludge samples were determined by the Walkley-Black procedure as described by Allison, et al., (1965). Total nitrogen concentrations were determined by the semimicro-Kjeldahl method as discussed by Bremner (1965). The ammonium saturation method, in accordance with Chapman's (1965) directions, was used to determine soil cation-exchange capacities.

Samples of corn leaves, opposite and below the primary ear shoots, were collected when about 10% of the plants had tasseled. Leaf samples were washed in distilled water immediately after cutting, dried at 60°C, and ground in a Wiley mill to pass a 20-mesh screen. Corn yields were determined by hand-harvesting the two center rows from each plot. Grain samples were collected from larger shelled-grain samples used to determine yield response. After stalk counts were made on plots, twenty-five growing plants were randomly selected and harvested from the two center rows and weighed. From the twenty-five plants, four were randomly selected for moisture determinations and analyses for chemical constituents. Both grain and chopped stover samples were dried and ground in the same manner as leaf samples. Leaf, grain, and stover subsamples (2 g) were wet ashed in concentrated HNO_3 at 90°C, followed by $HClO_4$ at 200°C, taken to dryness and dissolved in 1.0 N HNO_3 for determining metal concentrations by atomic absorption spectrophotometry. Total N and P concentrations in plants were determined respectively by a standard Kjeldahl (AOAC, 1970) and the vanadate-molybdate-yellow methods.

DATA HANDLING

The scheme by which water data were collected and treated is conceptually depicted in Figure 1. The physical aspects of collecting water samples were briefly discussed above, but it should be recognized that the samples were collected by a systematic sampling plan, as contrasted to random and stratified random sampling plans. That is to say, the first sample to be collected during any runoff or drainage event was chosen and then a sample was collected each time an amount of flow equal to 78 liters from the lysimeter surface and 26 liters from the lysimeter drainage tiles was delivered to the tipping buckets. To our knowledge, this is the first and may still be the only field lysimeter equipped to provide observations from discrete volumes of flow. In the past, most sampling of lysimeter waters was conducted by a more or less random sampling plan since all or some of the water from a flow event was collected in containers from which subsamples were withdrawn. In other cases, lysimeter flows were automatically sampled on a unit time basis. Neither of these methods of sampling provide opportunities for observing changes in water quality parameters which change with flow rates or volumes of flow.

Following the preparation and analysis of water samples, all raw data except for pH determinations required some calculations to transform them to standard reportable units. Most of the calculations were performed on an electronic desk calculator. After the data were converted to reportable units, they were punched on cards and stored on disk. Then from disk, an IBM sort/merge routine was used to group data according to kind of water (runoff or drainage), soil type, soil treatment, and period of time (an observation year began on May 1 and continued to April 30). After checking for discrepancies, the data were sorted again to arrange them in order of lowest to the highest value of a measured water quality parameter (data ranking), where below detectable level values were entered as one magnitude less than the

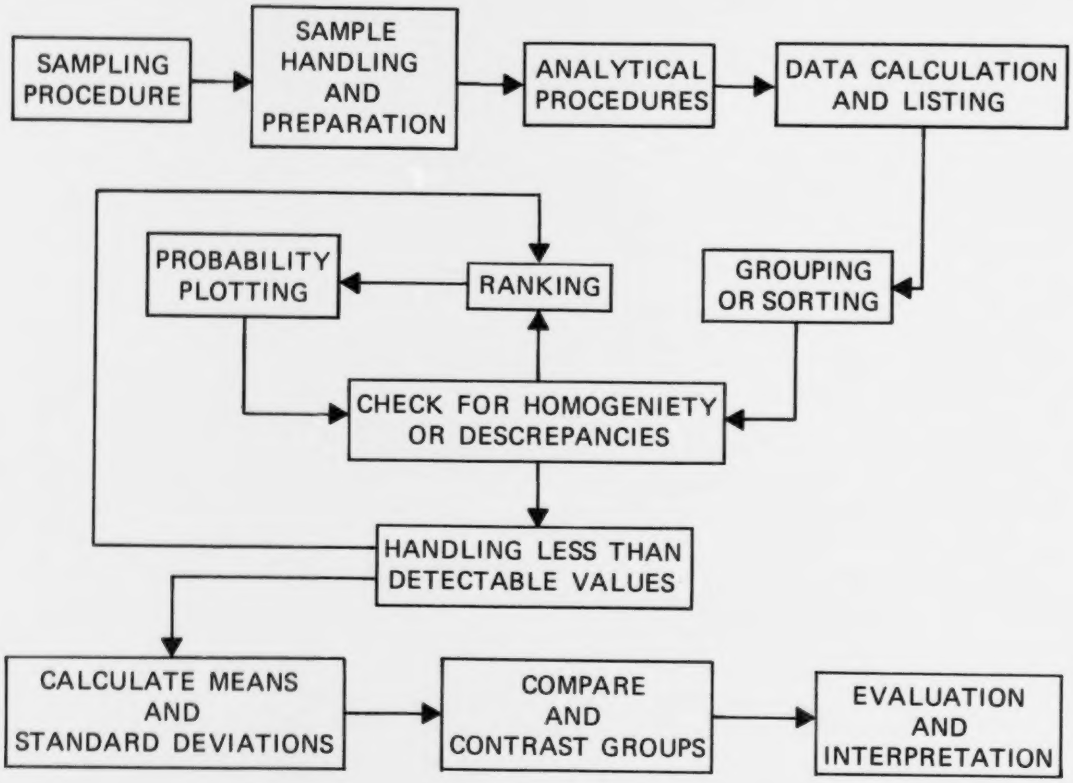
SAMPLING PROCEDURE
SAMPLE HANDLING AND PREPARATION
ANALYTICAL PROCEDURES
DATA CALCULATION AND LISTING
PROBABILITY PLOTTING
RANKING
GROUPING OR SORTING
CHECK FOR HOMOGENIETY OR DESCREPANCIES
HANDLING LESS THAN DETECTABLE VALUES
CALCULATE MEANS AND STANDARD DEVIATIONS
COMPARE AND CONTRAST GROUPS
EVALUATION AND INTERPRETATION

Figure 1. Sequence for sample handling and data treatment.

lowest detectable level. For example, Cd concentrations could not be detected below 0.001 ppm in water samples, but were entered as concentrations of 0.0001 ppm as a means of including them in the total number, N, of observations. From the number of ranked data points, N, the cumulative percent groups were calculated from lowest to highest by $\left(\frac{n_i}{N}\right) 100$, where n_i is the "i"th rank in a group of N data. Following the ranking of data within groups and assignment of cumulative percentiles of each datum, log-normal probability graphs were generated using a computer program developed in FORTRAN language and a Calcomp plotter. Where the number of observations were equal to or greater than 100, only a representative portion of the plotted points were depicted on the graphs. That is symbols were not drawn for all plotted values. Less than detectable values were included in the calculation of percentile distributions, but were not shown in graphs. Data are log-normally distributed when their logarithms fit a normal (Gaussian) distribution. For the log-normal probability plots presented here, the ordinate is a logarithmic scale of measured values and the abscissa is the probability scale where the frequency of a measured value x is expressed as a percent of occurrences equal to or less than the specified value. Many kinds of data exhibit log-normally distributed concentrations and can be collectively described as members of a homogenous group by a single central value and a variance (Aitchison and Brown, 1957). When log x concentrations or other appropriate units of measured water quality parameters are plotted versus the percent of the population of observations having values $\leq x$, on log-probability paper, a straight line is the best fit to the plotted points when the distribution of the population of values is log-normal. From this straight line, the estimated geometric mean ($\hat{\mu}$) is given by the fiftieth cumulative percent intercept while the estimated standard geometric deviation is indicated by the slope of the line. The estimated standard geometric deviation $\hat{\sigma}$ is often calculated as the ratio between values for cumulative percent intercepts of either 84.13 and 50 or 50 and 15.87, where either of the ratios corresponds to a whole unit of standard deviation. More exactly, the estimated standard geometric deviation $\hat{\sigma}$ is obtained from

$$\log \hat{\sigma} = \log x_{0.8413} - \log x_{0.50} = \log \frac{x_{0.8413}}{x_{0.50}}$$

or

$$\log \hat{\sigma} = \log x_{0.50} - \log x_{0.1587} = \log \frac{x_{0.50}}{x_{0.1587}}$$

In the same way that 68.3, 95.5, and 99.7 percent of the area under a normal distribution curve are located, respectively, in the ranges $x \pm s$, $x \pm 2s$, and $x \pm 3s$ (where "s" is the standard deviation), confidence intervals for the estimation of the true value of x can be calculated when the frequency distribution of log x is presumed to be a normal "error" distribution. The difference in calculating confidence limits is that the estimated standard deviation for a normally distributed population is an added and subtracted factor, whereas the antilog of the estimated geometric standard deviation is a multiplying and dividing factor applied to the antilog of the estimated geometric mean. More specifically, the intervals between $\hat{\mu} \times \hat{\sigma}$ and $\hat{\mu} \div \hat{\sigma}$,

$\hat{\mu} \times \hat{\sigma}^2$ and $\hat{\mu} \div \hat{\sigma}^2$, and $\hat{\mu} \times \hat{\sigma}^3$ and $\hat{\mu} \div \hat{\sigma}^3$ are estimates of boundaries containing 84.1, 97.5, and 99.9 percent, respectively, of the total number of observations from a log-normal distributed population.

Rather than fit a straight line to all the log-normal probability graphs, it was more convenient to compute both the estimated geometric mean and geometric standard deviation values for the several measured water quality parameters. The estimated geometric means ($\hat{\mu}$) were calculated by the formula:

$$\log \hat{\mu} = \frac{\log x_1 + \log x_2 + \log x_3 \ldots \log x_n}{N}$$

where x_1, x_2, x_3 . . . x_n are values of individual observations, or are values one magnitude less than the lowest detectable concentration level. Using the computer generated estimated geometric mean values, estimated geometric standard deviations were computer calculated by the formula:

$$\log \hat{\sigma} = \sqrt{\sum_{i=1}^{n} (\log x_i - \log \hat{\mu})^2 / N-1}$$

where x_i, i=1, 2, 3 . . . n are the values determined from N observations.

For purposes of comparison, other measurements of central tendency, such as the median, arithmetic mean, and the standard deviation associated with arithmetic mean values for water quality measurements were also calculated. It was noted that in the majority of cases, the arithmetic average or mean values were larger than either the geometric mean or median values. Although the geometric mean, like the arithmetic mean, is a mathematical rather than a positional average, the way in which individual measured values enter into the calculation of the geometric mean causes less weight to be given to extreme values. Thus, unless the numbers being averaged all have the same value, the geometric mean will always be less than the arithmetic mean. The median value is often an appropriate measure of central tendency for random variables which are not symmetrically distributed. Like the geometric mean, the median is not as sensitive to a small number of extreme values as is the arithmetic mean. The median is the mid-point value that divides in exactly one half the random variable values that are higher or lower values than itself. To minimize space requirements, the results from water quality measurements are discussed here only in terms of geometric means. Furthermore, only data from control and maximum-sludge-treated plots are presented. Results from measuring the several water quality parameters of runoff and drainage waters from less sludge-treated (¼-maximum and ½-maximum) soils were collected through 1974, but these data were not included in the report because they would not alter the conclusions derived from those obtained from maximum-sludge-treated plots. Total numbers of observations, N, for each of the water quality measurements made during each of the data years from water samples collected from the control and maximum-sludge-treated lysimeter plots are presented in Table 1.

(continued on Page 33)

(continued on page 33)

TABLE 1. NUMBER OF OBSERVATIONS FOR SEVERAL WATER QUALITY PARAMETERS IN RUNOFF AND DRAINAGE WATER SAMPLES COLLECTED FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS DURING THE PERIOD MAY 1 TO APRIL 30 FOR THE DATA YEARS BETWEEN 1971 TO 1977*

			Runoff water			Drainage water		
Water quality parameter	Year	Location and treatment	Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
Total Solids	1971-72	S1	53	57	16	91	51	227
		N1	74	51	21	39	72	132
		S4	94	25	12	164	59	6
		N4	64	16	19	111	28	58
	72-73	S1	96	77	41	149	52	283
		N1	86	51	31	80	199	209
		S4	101	26	26	190	95	35
		N4	63	34	29	317	29	135
	73-74	S1	57	49	35	172	41	185
		N1	36	74	21	124	206	190
		S4	54	18	19	232	65	44
		N4	20	22	22	253	34	136
	74-75	S1	39	40	28	79	48	74
		N1	6	33		13	63	8
		S4	56	24	13	111	37	32
		N4	8	15	16	61	21	29
	75-76	S1	37	25	27	55	44	58
		N1		20			60	
		S4	37	18	8	101	36	22
		N4		16	5	83	23	20

(continued)

TABLE 1. (continued)

			Runoff water			Drainage water		
Water quality parameter	Year	Location and treatment	Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
Total Solids	76-77	S1	8	4	4	11	4	7
		N1		7			9	
		S4	8	3	2	12	3	3
		N4		4	3	8	5	3
Organic-C	72-73	S1	5		2			16
		N1	3	3			6	9
		S4	4			6	3	
		N4	2		2	16	2	7
	73-74	S1						
		N1						
		S4						
		N4						
	74-75	S1				4	3	4
		N1					3	
		S4				7	2	2
		N4				5	2	2
	75-76	S1	19	13	21	35	32	38
		N1		20			42	
		S4	26	13	3	57	20	15
		N4		11	5	36	20	17

(continued)

p. 2

TABLE 1. (continued)

			Runoff water			Drainage water		
Water quality parameter	Year	Location and treatment	Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
Organic-C	76-77	S1						
		N1		7				
		S4						
		N4		6			2	
Conductivity	71-72	S1	60	67	17	117	60	347
		N1	84	56	21	69	136	239
		S4	112	27	14	214	78	14
		N4	73	18	22	176	32	109
	72-73	S1	134	114	59	206	62	537
		N1	117	79	44	121	335	404
		S4	151	44	36	264	142	54
		N4	80	42	45	481	33	226
	73-74	S1	66	62	37	243	59	308
		N1	37	79	24	182	335	310
		S4	64	22	21	354	131	75
		N4	27	27	25	426	39	200
	74-75	S1	41	38	32	104	60	113
		N1	6	31	2	18	96	8
		S4	61	29	11	153	48	43
		N4	8	13	16	92	26	51

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water			Drainage water		
			Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
Conductivity	75-76	S1	40	37	35	139	78	115
		N1		25			143	
		S4	44	23	7	130	63	44
		N4		19	5	186	30	59
	76-77	S1	9	4	4	11	4	8
		N1		13			9	
		S4	9	4	2	14	3	4
		N4		8	3	9	5	3
pH	71-72	S1	33	38	11	72	33	208
		N1	44	26	14	18	47	73
		S4	80	19	8	153	71	
		N4	34	9	9	71	15	38
	72-73	S1	64	48	32	64	17	173
		N1	53	31	12	27	126	114
		S4	70	15	14	71	51	8
		N4	33	20	21	172	13	71
	73-74	S1	13	11	13	50	13	62
		N1	11	28	9	18	45	32
		S4	26	5	9	86	36	4
		N4	6	8	14	67	7	28

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water Blount silt loam	Runoff water Elliott silt loam	Runoff water Plainfield loamy sand	Drainage water Blount silt loam	Drainage water Elliott silt loam	Drainage water Plainfield loamy sand
NO_3-N	71-72	S1	58	57	16	104	57	258
		N1	83	56	21	66	134	231
		S2	6		3	136	16	125
		N2	5	2		178	56	40
		S3	9	2	2	163	21	100
		N3	4	3	2	52	29	31
		S4	65	21	11	138	33	11
		N4	68	16	19	155	25	96
	72-73	S1	129	113	60	201	60	525
		N1	118	78	43	114	329	396
		S4	150	43	34	257	132	53
		N4	79	42	45	474	33	216
	73-74	S1	65	63	37	244	60	308
		N1	37	79	24	187	335	318
		S4	65	22	21	355	132	75
		N4	26	27	25	427	39	201
	74-75	S1	41	38	32	104	60	110
		N1	6	31	2	18	96	8
		S4	61	29	11	154	48	40
		N4	8	13	16	93	27	51

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water: Blount silt loam	Runoff water: Elliott silt loam	Runoff water: Plainfield loamy sand	Drainage water: Blount silt loam	Drainage water: Elliott silt loam	Drainage water: Plainfield loamy sand
NO_3-N	75-76	S1	40	37	35	139	78	115
		N1		25			144	
		S4	44	23	7	131	63	44
		N4		18	5	188	32	59
	76-77	S1	10	4	3	11	4	8
		N1		12			9	
		S4		4		13	2	4
		N4	9	9	3	9	6	3
NH_4-N	72-73	S1	69	61	40	97	19	
		N1	66	46	28	44	188	192
		S4	125	30	32	137	66	
		N4	67	38	40	287	16	127
	73-74	S1	30	28	11	132	25	129
		N1	18	35		83	168	132
		S4	34	9	8	224	78	28
		N4	11	14		208	21	97
	74-75	S1				47	21	40
		N1		10		12		6
		S4				49	21	23
		N4		8		21		20

(continued)

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TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water			Drainage water		
			Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
P	71-72	S1	38	45	9	37	21	96
		N1	44	29	14	13	28	43
		S4	60	16	9	83	34	3
		N4	38	11	12	47	15	19
	72-73	S1	106	93	54	110	38	375
		N1	102	66	38	146	170	185
		S4	121	33	28	152	87	25
		N4	66	36	33	241	21	116
	73-74	S1	47	49	27	175	51	187
		N1	34	69	22	139	239	159
		S4	53	17	17	249	103	42
		N4	20	23	22	320	33	118
	74-75	S1	36	36	25	84	47	82
		N1	6	28		17	79	8
		S4	51	23	9	109	45	32
		N4	3	12	15	72	23	43
	75-76	S1	17	12	15	70	50	51
		N1		9			57	
		S4	21	7	5	58	36	27
		N4		8	2	67	15	34

(continued)

TABLE 1. (continued)

			Runoff water			Drainage water		
Water quality parameter	Year	Location and treatment	Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
P	76-77	S1	10			6		
		N1		7				
		S4	10					
		N4		7			2	
K	71-72	S1	40	45	10	41	22	91
		N1	47	31	15	15	31	50
		S4	59	14	8	70	29	3
		N4	42	12	12	52	15	20
	72-73	S1	106	88	52	109	42	375
		N1	99	59	34	55	206	210
		S4	116	30	28	158	89	28
		N4	59	35	35	304	23	136
	73-74	S1	47	48	25	184	51	208
		N1	32	64	20	140	255	173
		S4	54	16	19	268	110	44
		N4	19	20	22	335	29	125
	74-75	S1	27	28	26	69	41	78
		N1	6	25		17	63	8
		S4	38	18	9	93	39	30
		N4	5	14	14	52	19	42

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water Blount silt loam	Runoff water Elliott silt loam	Runoff water Plainfield loamy sand	Drainage water Blount silt loam	Drainage water Elliott silt loam	Drainage water Plainfield loamy sand
K	75-76	S1	39	35	36	103	74	101
		N1		36			90	
		S4	50	26	11	104	54	33
		N4		24	8	121	28	42
	76-77	S1	5			9	2	6
		N1		5			6	
		S4	3	2		11	2	4
		N4		3		9	3	3
Na	71-72	S1	26	35	9	19	14	65
		N1	34	26	11	5	10	41
		S4	49	12	6	30	15	3
		N4	35	10	11	22	6	16
	72-73	S1	92	81	49	122	42	384
		N1	95	59	30	71	217	217
		S4	106	32	27	171	92	32
		N4	56	34	31	326	23	147
	73-74	S1	44	40	23	112	31	152
		N1	28	65	17	97	151	142
		S4	43	14	16	145	49	32
		N4	18	20	21	201	28	93

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water: Blount silt loam	Runoff water: Elliott silt loam	Runoff water: Plainfield loamy sand	Drainage water: Blount silt loam	Drainage water: Elliott silt loam	Drainage water: Plainfield loamy sand
Na	74-75	S1	10	8	7	50	34	54
		N1	2	5		13	48	6
		S4	18	8	3	70	25	23
		N4	4	5	6	32	14	30
	75-76	S1	36	31	32	106	71	101
		N1		33			95	
		S4	45	26	10	97	51	37
		N4		21	8	127	28	42
	76-77	S1	5			10	2	7
		N1		5			7	
		S4	3	2		11	2	4
		N4		3		8	3	3
Fe	71-72	S1	40	46	12	41	24	96
		N1	52	32	16	15	31	50
		S4	62	16	9	85	35	3
		N4	42	13	13	51	16	14
	72-73	S1	108	88	54	126	43	392
		N1	107	64	37	57	216	214
		S4	124	33	30	167	93	31
		N4	66	37	36	315	24	140

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water Blount silt loam	Runoff water Elliott silt loam	Runoff water Plainfield loamy sand	Drainage water Blount silt loam	Drainage water Elliott silt loam	Drainage water Plainfield loamy sand
Fe	73-74	S1	52	52	28	183	51	209
		N1	34	70	22	147	259	177
		S4	59	17	19	268	111	43
		N4	21	21	22	336	33	126
	74-75	S1	35	37	28	87	50	84
		N1	6	31		17	74	8
		S4	58	23	11	115	46	31
		N4	5	14	15	66	21	43
	75-76	S1	37	35	36	106	76	96
		N1		36			81	
		S4	47	25	11	104	55	38
		N4		21	8	131	26	41
	76-77	S1	8	3	4	13	3	8
		N1		8			8	
		S4	8	4	2	14	3	4
		N4		4	3	9	3	3
Mn	71-72	S1	38	44	9	37	20	91
		N1	48	30	13	14	28	49
		S4	54	14	9	47	17	3
		N4	38	13	12	45	13	18

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water Blount silt loam	Runoff water Elliott silt loam	Runoff water Plainfield loamy sand	Drainage water Blount silt loam	Drainage water Elliott silt loam	Drainage water Plainfield loamy sand
Mn	72-73	S1	103	86	49	127	44	406
		N1	103	58	37	57	221	230
		S4	118	35	28	166	91	31
		N4	66	35	34	321	24	140
	73-74	S1	53	51	27	181	51	203
		N1	35	70	22	147	257	171
		S4	57	18	20	269	110	43
		N4	21	23	22	330	32	123
	74-75	S1	36	37	27	85	49	87
		N1	6	31		17	72	8
		S4	58	23	11	114	46	31
		N4	5	14	15	66	21	44
	75-76	S1	40	34	37	108	77	101
		N1		36			91	
		S4	49	27	11	104	55	38
		N4		23	8	130	28	39
	76-77	S1	9	3	4	12	3	8
		N1		8			8	
		S4	8	4	2	14	3	4
		N4		4	3	9	4	3

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water: Blount silt loam	Runoff water: Elliott silt loam	Runoff water: Plainfield loamy sand	Drainage water: Blount silt loam	Drainage water: Elliott silt loam	Drainage water: Plainfield loamy sand
Zn	71-72	S1	40	46	12	42	24	99
		N1	52	30	16	14	30	50
		S4	62	16	9	91	33	3
		N4	42	13	13	52	15	21
	72-73	S1	109	91	54	124	43	405
		N1	106	65	39	53	221	233
		S4	123	35	30	167	92	31
		N4	68	38	37	324	24	143
	73-74	S1	53	52	28	179	48	208
		N1	34	71	22	134	250	170
		S4	59	18	20	265	107	43
		N4	21	21	21	321	30	124
	74-75	S1	36	37	28	89	50	90
		N1	6	31		17	73	8
		S4	58	23	11	113	46	31
		N4	5	14	15	66	21	44
	75-76	S1	40	33	36	106	74	87
		N1		37			93	
		S4	47	27	10	108	48	35
		N4		25	8	127	28	42

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water: Blount silt loam	Runoff water: Elliott silt loam	Runoff water: Plainfield loamy sand	Drainage water: Blount silt loam	Drainage water: Elliott silt loam	Drainage water: Plainfield loamy sand
Zn	76-77	S1	8	3	4	12	3	8
		N1		8			8	
		S4	8	4	2	14	3	4
		N4		3	3	8	4	3
Cd	71-72	S1	26	27	6	36	16	56
		N1	32	18	13	14	28	19
		S4	44	13	8	83	31	3
		N4	20	9	7	43	14	10
	72-73	S1	109	90	54	128	44	398
		N1	100	63	36	57	222	219
		S4	124	35	30	167	93	31
		N4	66	37	34	324	24	145
	73-74	S1	54	52	28	184	51	210
		N1	34	71	22	147	261	177
		S4	59	18	20	269	111	44
		N4	21	22	22	337	33	127
	74-75	S1	36	37	28	89	49	90
		N1	6	31		17	73	8
		S4	56	23	11	112	46	32
		N4	5	14	15	69	21	44

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water: Blount silt loam	Runoff water: Elliott silt loam	Runoff water: Plainfield loamy sand	Drainage water: Blount silt loam	Drainage water: Elliott silt loam	Drainage water: Plainfield loamy sand
Cd	75–76	S1	35	32	30	99	72	93
		N1		34			81	
		S4	41	24	9	100	52	38
		N4		23	8	111	26	40
	76–77	S1	7	3	4	9		6
		N1		8			7	
		S4	8	3	2	11	2	3
		N4		4	3	8	4	3
Cu	71–72	S1	40	45	12	40	24	97
		N1	52	32	16	14	30	48
		S4	63	16	9	91	37	3
		N4	42	13	13	53	16	21
	72–73	S1	108	91	53	126	44	407
		N1	105	64	39	57	222	225
		S4	124	35	30	168	94	31
		N4	68	37	37	321	24	144
	73–74	S1	54	52	28	180	51	211
		N1	34	71	22	147	261	176
		S4	59	18	20	270	111	44
		N4	21	23	22	332	33	127

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water			Drainage water		
			Blount silt loam	Elliott silt loam	Plainfield loamy sand	Blount silt loam	Elliott silt loam	Plainfield loamy sand
Cu	74-75	S1	36	37	28	89	50	90
		N1	6	31		17	74	8
		S4	53	23	11	113	45	31
		N4	5	13	11	66	21	44
	75-76	S1	46	36	39	110	78	103
		N1		36			96	
		S4	51	28	10	115	56	38
		N4		25	8	133	30	42
	76-77	S1	18	3	4	20	3	8
		N1		7			8	
		S4	12	4	2	26	3	4
		N4		4	3	9	4	3
Ni	76-77	S1	17	3	4	21	3	7
		N1		8			8	
		S4	18	4	2	29	3	4
		N4		5	3	9	4	3
Cr	76-77	S1	10			9		
		N1		3				
		S4	5			13		
		N4						

(continued)

TABLE 1. (continued)

Water quality parameter	Year	Location and treatment	Runoff water Blount silt loam	 Elliott silt loam	 Plainfield loamy sand	Drainage water Blount silt loam	 Elliott silt loam	 Plainfield loamy sand
Pb	76-77	S1	2					
		N1		2				
		S4	2					
		N4						
Se	76-77	S1	5			4		
		N1						
		S4	3			5		
		N4					2	
As	76-77	S1	3			4		
		N1						
		S4	2			6		
		N4					3	
Sb	76-77	S1	4			8		
		N1						
		S4	3			10		
		N4					2	
Hg	76-77	S1				5		
		N1						
		S4	3			9		
		N4					3	

*Water samples were collected from fertilized and irrigated control or check plots, 1, maximum-sludge-treated plots, 4, located in either a north, N, or south, S, series.

TABLE 2. ANNUAL AMOUNTS (DRY WT) OF SLUDGE CONSTITUENTS APPLIED ON MAXIMUM-TREATED PLOTS OF BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS.*

Year	Solids	Total N	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb
	mt/ha	kg/ha													
								North Series							
1969	16.4	1134	819			448	243	860	5	158	7.9	36	10.7	102	23
1970	52.8	2902	2067			1361	821	2734	17	427	22.6	101	22.1	266	100
1971	57.8	3532	1984	535	246	2062	546	2526	17	265	13.2	69	15.6	161	71
1972	44.4	2292	1174	252	204	2248	545	1825	21	192	7.8	33	4.3	54	46
1973	61.1	3286	2000	359	414	2770	653	2067	32	248	6.8	41	5.2	87	55
1974	69.8	4933	2717	361	284	2055	722	3190	30	359	21.8	117	24.2	210	65
1975	54.0	3367	1681	343	207	1641	677	2607	26	245	13.4	85	21.3	170	60
1976	72.0	3989	2343	403	269	1992	858	3301	40	273	19.2	127	32.1	219	66
								South Series							
1969	19.3	813	805			399	190	455	4	122	5.2	27	7.7	79	14
1970	36.2	2329	1187			989	570	1723	10	312	22.2	69	14.5	174	100
1971	104.7	3636	3010	963	395	3287	876	3967	25	464	24.0	114	28.2	298	124
1972	32.2	1650	943	168	186	1342	414	1239	14	135	5.8	22	3.1	40	30
1973	58.8	3202	1796	370	379	2831	653	2041	31	224	6.7	38	7.6	76	52
1974	70.7	4803	2663	357	291	1868	725	3339	37	350	21.7	114	22.6	205	75
1975	52.4	3367	1681	343	207	1641	677	2607	26	245	13.4	85	21.3	170	60
1976	71.3	4604	2412	396	248	1987	870	3301	45	273	19.1	115	30.9	226	66

* After the 1973 growing season sludge applications were terminated on all plots in the north series except maximum-treated Elliott silt loam and Plainfield loamy sand plots.

DISCUSSION OF RESULTS

Sludge Loading Rates

The solids content of the digested sludge applied on lysimeter plots ranged from about 1.5 to 3% and weather conditions dictated the frequency at which the liquid suspension could be applied on plots. Because of these factors, amounts of solids applied on plots varied from year to year. Annual amounts of sludge solids and other constituents applied on maximum-treated plots are shown on Table 2. Appropriately lesser amounts from a particular tank of sludge were applied on ¼- and ½- maximum-treated plots. Amounts of sludge-borne constituents varied from one year to the next even when similar amounts of sludge solids were applied.

Concentrations of several sludge constituents for which annual loading rates are presented (Table 2) were monitored in drainage and runoff water from the time the study was initiated. Beginning in 1976 water samples were analyzed for Se, As, Sb, and Hg, even though concentrations of these elements in sludges were relatively low. Results from samples collected over a period of six years show that mean concentrations of Se, As, Sb, and Hg in digested sludge were 5.7± 4.9, 19.8±2.3, 1.3±0.5 and 4.4±2.0 ppm (dry wt.), respectively. About 2.5-, 8.4-, 0.5-, and 2.0- kg/ha of sludge-borne Se, As, Sb, and Hg, respectively, were applied on maximum-treated plots, beginning with the 1969 and ending with the 1976 growing seasons.

Changes in Water Quality

Variability in Concentration-Nutrients and Trace Elements

Comparison of geometric means of data from sludge-treated plots to those from control plots were made to determine possible significant differences in water quality due to treatment. Data were prepared according to sampling year, kind of water (runoff or drainage), soil type, and location of plots in north or south series. Tests for significant differences between two treatments within each group were based on the t-distribution. Values for t for a log-normal distribution were calculated and significant differences in geometric means due to treatment were determined from a table of the distribution of t for two-tailed tests (Snedecor and Cochran, 1967, p. 549).

Geometric mean levels for several water quality changes attributable to annual sludge applications during the period 1971 to 1977 are summarized in Table 3 in runoff and table 4 for drainage water. Concentrations of total solids were higher only in runoff water from sludge-treated plots of Plainfield loamy sand in the north series, as compared to those in water from control plots. But sludge applications caused higher total solids concentrations in drainage water from all soil types. Soluble organic carbon concentrations were not changed in runoff water, but were significantly increased in drainage water from Blount and Elliott silt loam soils by sludge applications. Sludge treatments increased conductivity in runoff water from Blount silt loam soil and in drainage water from all three soil types. Nitrate nitrogen concentrations were significantly

TABLE 3. GEOMETRIC MEAN LEVELS ($\hat{\mu}$) AND STANDARD DEVIATIONS ($\hat{\sigma}$) FOR SEVERAL WATER QUALITY PARAMETERS AS DETERMINED IN RUNOFF WATER SAMPLES FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS DURING THE PERIOD 1971-77.a/b/c/

Parameter	Treatment							
	S1		S4		N1		N4	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
	Blount silt loam							
Total Solids (%)	0.076	3.03	0.079	2.49	0.076	4.01	0.071	2.72
Org-C	30.135	1.99	25.067	1.45	---	---	---	---
EC (mmho/cm)	0.259	1.81	0.404**	1.83	0.228	1.76	0.340**	1.70
pH (units)	7.5	1.1	7.4**	1.1	7.5	1.1	7.4*	1.0
NO_3-N	4.6	2.8	11.0**	3.1	3.5	2.3	8.6**	2.3
NH_4-N	0.386	3.08	0.669**	6.37	0.509	4.28	0.875**	6.89
P	1.353	2.52	1.819**	2.36	1.360	3.06	1.981**	2.56
K	8.83	2.24	13.58**	2.60	9.37	2.64	10.85	2.67
Na	5.50	2.37	5.71	2.45	3.87	2.54	5.40**	2.44
Fe	11.61	4.94	8.19**	5.52	16.48	6.93	9.62**	4.97
Mn	0.289	5.65	0.182**	5.64	0.361	6.46	0.179**	4.67
Zn	0.083	4.32	0.144**	4.09	0.113	5.51	0.174*	4.30
Cd	0.005	4.90	0.010**	3.61	0.006	4.58	0.016**	3.92
Cu	0.029	3.06	0.065**	2.45	0.034	3.82	0.066**	2.90
Ni	0.035	15.74	0.186	10.78	---	---	---	---
Cr	0.007	3.47	0.006	1.91	---	---	---	---
Pb	0.015	1.00	0.015	1.00	---	---	---	---
Se (ppb)	0.07	1.00	0.60	3.13	---	---	---	---
As (ppb)	13.84	2.64	9.99	1.13	---	---	---	---
Sb (ppb)	0.33	1.00	0.33	1.00	---	---	---	---
Hg (ppb)	0.57	1.19	0.67	1.51	---	---	---	---

(continued)

TABLE 3. (continued)

Parameter	Treatment							
	S1		S4		N1		N4	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
	----------Elliott silt loam----------							
Total Solids (%)	0.068	3.08	0.066	2.34	0.100	4.04	0.125	3.94
Org-C	28.253	1.60	22.143	1.78	26.738	1.90	43.570	1.52
EC (mmho/cm)	0.253	1.82	0.285	2.08	0.226	1.73	0.215	1.80
pH (units)	7.3	1.1	7.1*	1.1	7.4	1.1	7.0**	1.1
NO_3-N	5.3	2.8	9.1**	3.4	4.4	2.8	4.7	3.4
NH_4-N	0.505	3.33	1.147**	3.47	0.513	3.08	1.136**	3.48
P	1.330	2.69	1.398	2.32	1.333	2.62	1.982**	2.10
K	9.61	2.43	8.92	2.47	9.35	2.11	11.27*	2.06
Na	7.18	2.72	5.23	2.32	4.51	2.42	2.86	2.34
Fe	9.30	4.95	7.47	4.67	12.60	6.96	19.65*	5.86
Mn	0.256	5.56	0.217	4.78	0.341	6.32	0.528*	4.65
Zn	0.072	4.18	0.130**	2.70	0.111	4.23	0.314**	3.42
Cd	0.005	5.66	0.008**	3.75	0.004	4.75	0.015**	3.55
Cu	0.026	3.40	0.044**	2.27	0.034	3.19	0.099**	2.78
Ni	0.008	1.77	0.008	1.36	0.006	2.14	0.255	12.32
Cr	---	---	---	---	0.004	1.11	---	---
Pb	---	---	---	---	0.015	1.00	---	---
Se (ppb)	---	---	---	---	---	---	---	---
As (ppb)	---	---	---	---	---	---	---	---
Sb (ppb)	---	---	---	---	---	---	---	---
Hg (ppb)	---	---	---	---	---	---	---	---

(continued)

TABLE 3. (continued)

Parameter	Treatment							
	S1		S4		N1		N4	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
	----------------------------Plainfield loamy sand----------------------------							
Total Solids (%)	0.087	3.49	0.085	3.18	0.048	2.93	0.112**	4.39
Org-C	23.981	2.15	21.210	2.76	---	---	16.031	1.41
EC (mmho/cm)	0.239	2.02	0.227	1.93	0.184	1.91	0.199	1.76
pH (units)	7.4	1.1	7.4	1.1	7.2	1.1	7.5	1.1
NO_3-N	4.7	3.4	5.7	3.1	4.8	2.7	2.9	3.1
NH_4-N	0.404	3.23	0.534	3.19	0.868	2.38	0.794	5.64
P	1.476	2.64	1.751	2.56	1.837	2.41	2.879**	3.27
K	9.55	1.92	9.40	2.49	8.68	2.58	11.39*	2.13
Na	3.98	2.85	2.99	2.60	2.83	2.54	3.33	2.33
Fe	8.64	6.89	11.91	5.98	9.12	5.85	22.96**	6.70
Mn	0.235	7.00	0.250	5.53	0.249	5.29	0.500*	6.61
Zn	0.101	5.00	0.171*	3.80	0.100	3.87	0.356**	4.81
Cd	0.006	3.82	0.008	4.47	0.005	4.17	0.016**	4.85
Cu	0.033	3.62	0.072**	2.62	0.023	3.67	0.101**	3.30
Ni	0.008	1.49	0.028	1.27	---	---	0.012	1.35
Cr	---	---	---	---	---	---	---	---
Pb	---	---	---	---	---	---	---	---
Se (ppb)	---	---	---	---	---	---	---	---
As (ppb)	---	---	---	---	---	---	---	---
Sb (ppb)	---	---	---	---	---	---	---	---
Hg (ppb)	---	---	---	---	---	---	---	---

a/ Results are reported in ppm unless otherwise noted.

b/ Samples were collected from fertilized and irrigated control or check plots, 1, and maximum-sludge-treated plots, 4, in either a north, N, or south, S, series of plots adjacent to an instrument house.

c/ Beginning in 1977 samples were collected from only the Blount check and max plots on the south side and Elliott check and max plots on the north side.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

--- Insufficient data.

TABLE 4. GEOMETRIC MEAN LEVELS ($\hat{\mu}$) AND STANDARD DEVIATIONS ($\hat{\sigma}$) FOR SEVERAL WATER QUALITY PARAMETERS AS DETERMINED IN DRAINAGE WATER SAMPLES FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS DURING THE PERIOD 1971-77.a/b/c/

Parameter	Treatment							
	S1		S4		N1		N4	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
	---------------Blount silt loam---------------							
Total Solids (%)	0.095	1.78	0.196**	1.54	0.095	1.41	0.146**	2.09
Org-C	11.270	1.99	26.948**	1.78	---	---	10.992	1.78
EC (mmho/cm)	1.032	1.82	2.282**	1.50	1.146	1.42	1.752**	1.87
pH (units)	7.8	1.4	7.8	1.0	7.8	1.0	7.9	1.2
NO_3-N	34.3	2.9	145.5**	1.9	36.7	1.9	93.4**	3.11
NH_4-N	0.057	5.84	0.134**	5.61	0.052	4.82	0.061	5.29
P	0.222	5.62	0.366**	3.22	0.116	4.86	0.146*	3.93
K	3.67	2.44	5.77**	2.52	1.81	2.21	2.07*	2.48
Na	27.40	2.48	35.04**	1.85	25.67	1.35	21.66**	2.23
Fe	0.81	12.04	0.41**	6.40	0.32	15.83	0.20*	10.60
Mn	0.025	5.62	0.017**	2.95	0.015	4.91	0.017	3.59
Zn	0.023	3.86	0.041**	2.76	0.017	4.23	0.019	2.92
Cd	0.004	4.46	0.007**	3.05	0.005	4.02	0.005	4.57
Cu	0.011	2.95	0.026**	2.57	0.011	3.18	0.012	2.60
Ni	0.012	4.11	0.033*	4.45	---	---	0.006	1.94
Cr	0.005	2.41	0.010*	1.32	---	---	---	---
Pb	---	---	---	---	---	---	---	---
Se (ppb)	0.24	4.48	0.54	3.33	---	---	---	---
As (ppb)	7.23	1.97	2.97	1.34	---	---	---	---
Sb (ppb)	0.48	1.68	0.40	1.48	---	---	---	---
Hg (ppb)	0.38	1.26	0.46	1.53	---	---	---	---

(continued)

TABLE 4. (continued)

Parameter	Treatment							
	S1		S4		N1		N4	
	μ	σ	μ	σ	μ	σ	μ	σ
	Elliott silt loam							
Total Solids (%)	0.069	1.65	0.222**	1.50	0.073	1.54	0.167**	1.90
Org-C	9.081	1.61	28.101**	2.03	12.790	2.05	23.847**	2.16
EC (mmho/cm)	0.823	1.55	2.492**	1.70	0.880	1.68	1.730**	1.89
pH (units)	8.1	1.0	7.7**	1.1	8.1	1.0	7.8**	1.0
NO_3-N	20.1	2.2	167.5**	1.7	23.8	2.1	116.7**	2.3
NH_4-N	0.070	6.14	0.137**	5.32	0.046	5.71	0.102**	5.25
P	0.366	2.54	0.866**	2.49	0.201	3.61	0.410**	2.57
K	4.20	1.80	6.36**	2.62	2.37	2.15	4.67**	2.24
Na	27.05	2.08	41.94**	1.61	15.49	1.88	28.48**	2.08
Fe	0.74	8.19	0.65	7.48	0.43	12.02	0.47	12.07
Mn	0.017	4.04	0.040**	3.76	0.018	5.82	0.027*	4.01
Zn	0.024	2.91	0.223**	2.55	0.014	4.44	0.047**	3.25
Cd	0.004	4.39	0.019**	2.75	0.004	4.99	0.006**	3.36
Cu	0.011	2.36	0.045**	2.51	0.008	3.77	0.022**	2.30
Ni	0.010	3.12	0.023	2.34	0.006	2.15	0.016	1.61
Cr	---	---	---	---	---	---	---	---
Pb	---	---	---	---	---	---	---	---
Se (ppb)	---	---	---	---	---	---	0.18	1.21
As (ppb)	---	---	---	---	---	---	5.35	2.94
Sb (ppb)	---	---	---	---	---	---	0.33	1.00
Hg (ppb)	---	---	---	---	---	---	0.54	1.58

(continued)

TABLE 4. (continued)

Parameter	Treatment							
	S1		S4		N1		N4	
	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
	------------------------------Plainfield loamy sand------------------------------							
Total Solids (%)	0.057	1.56	0.081**	1.68	0.055	1.499	0.110**	1.55
Org-C	7.671	1.93	11.014	1.80	---	---	8.411	1.91
EC (mmho/cm)	0.685	1.46	0.998**	1.59	0.655	1.327	1.313**	1.44
pH (units)	8.1	1.0	7.9	1.0	7.9	1.0	8.0	1.0
NO_3-N	18.6	1.8	46.1**	3.1	21.0	1.7	77.7**	1.9
NH_4-N	0.036	5.93	0.045	2.90	0.032	5.769	0.043*	4.02
P	0.433	2.46	0.419	1.68	0.353	3.018	0.242	2.02
K	8.32	2.24	11.98**	2.82	6.50	1.86	12.18**	1.81
Na	41.80	1.80	17.38	2.27	30.43	1.92	25.52	1.73
Fe	0.44	8.68	0.26**	5.84	0.74	9.44	0.22**	8.69
Mn	0.014	5.50	0.011	4.98	0.025	4.299	0.008**	3.94
Zn	0.013	4.17	0.020**	3.41	0.020	2.802	0.021	2.74
Cd	0.003	5.51	0.004**	4.50	0.003	5.513	0.005**	4.07
Cu	0.006	3.53	0.014**	2.63	0.006	3.062	0.009**	2.95
Ni	0.009	1.83	0.006	1.36	---	---	0.011	1.39
Cr	---	---	---	---	---	---	---	---
Pb	---	---	---	---	---	---	---	---
Se (ppb)	---	---	---	---	---	---	---	---
As (ppb)	---	---	---	---	---	---	---	---
Sb (ppb)	---	---	---	---	---	---	---	---
Hg (ppb)	---	---	---	---	---	---	---	---

a/ Results are reported in ppm unless otherwise noted.

b/ Samples were collected from fertilized and irrigated control or check plots, 1, and maximum-sludge-treated plots, 4, in either a north, N, or south, S, series of plots adjacent to an instrument house.

c/ Beginning in 1977 samples were collected from only the Blount check and max plots on the south side and Elliott check and max plots on the north side.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

--- Insufficient data.

higher in runoff waters from sludge-treated plots of Blount and from the south series of Elliott silt loam soils. Concentrations of NO_3-N were markedly increased in drainage as compared to runoff water from all soil types as a result of sludge treatments. The small differences in NO_3-N concentrations in drainage water from Plainfield loamy sand were evidently due to dilution. When Plainfield loamy sand plots were constructed, additional surface areas adjacent to the plots were excavated to a depth of 30 cm and filled with the loamy sand to decrease mixing with the native soil during tillage operations. It appears that the fiberglass border around the plots did not keep out the foreign water from the border area established to reduce mixing with the native Blount silt loam during tillage operations. About 50% more water entered the drainage system for Plainfield loamy sand plots than would have been the case if all foreign water had been excluded. Concentrations of NH_4-N in runoff waters from sludge-treated Blount and Elliott silt loam plots were higher than concentrations in similar samples from control plots. Sludge applications also increased NH_4-N concentrations in drainage waters from the Blount silt loam soils in the southern series, both series of Elliott silt loam plots, and Plainfield loamy sand plots in the north series. Compared to control plots, runoff water from sludge-treated plots contained higher concentrations of P, except for Elliott silt loam and Plainfield loamy sand plots in the south series. Drainage water samples from sludge-treated plots contained more P than similar waters from control plots of fine textured soils, but treatment differences were not observed in samples from the loamy sand plots. Potassium concentrations in runoff water were enhanced by sludge treatments on Blount silt loam in the south series and on Elliott silt loam and Plainfield loamy sand in the north series. Concentrations of K were increased in drainage waters from all soil types by sludge treatments. Only runoff water from Blount silt loam soil in the north series of plots had Na concentrations that were higher in samples from sludge-treated as compared to those collected from control plots. But drainage water from the Plainfield loamy sand plots were the only plots sampled which did not show higher concentrations of Na due to sludge-treatments. Concentrations of Fe in runoff water from sludge-treated plots were lower in samples from Blount silt loam soil and higher in samples from Elliott silt loam and Plainfield loamy sand plots located in the north series when compared to concentrations in samples from control plots. These inconsistencies for Fe concentrations were not observed in drainage water samples in that Fe concentrations were either not affected or were decreased by sludge applications. Similar inconsistencies were found for Mn concentrations in both runoff water and drainage water. Since treatments on Blount silt loam soil were replicated three times in both series of plots, the decreases in Fe and Mn concentrations associated with sludge-treatments on this soil type can be accepted with a great deal more confidence than the data from the other two soil types for which only control plots were replicated. Concentrations of Zn, Cd, and Cu in runoff and drainage water were either unaffected by sludge applications or were increased regardless of soil type. However, the significant increases in concentrations of these three metals were so low that differences due to treatment probably could not have been detected in the absence of the extensive water sampling program that was conducted during this study. Not enough data have been collected to adequately assess the effect of sludge applications on concentrations of Ni, Cr, Pb, Se, As, Sb, and Hg. From the data that have been obtained there is an indication that only Ni and Cr concentrations in effluent waters from sludge-treated sites may be increased slightly. Annual applications of sludge, over an eight year period, does not appear to have affected concentrations of Pb, Se, As, Sb, and Hg in water samples collected in 1976 to 1977.

Geometric mean levels by individual years for water quality parameters of runoff and drainage waters are presented in Tables 5 and 6, respectively. From an inspection of these data and those in Table 2 it is readily apparent that much of the year to year variation is due to differences in annual sludge loading rates. During the last 6 years of the study there was no evidence that any water quality parameter measured was deteriorating with increased years of annual sludge applications. It is also noteworthy, especially with regard to P and heavy metals, that concentrations of various elements in drainage waters from Plainfield loamy sands were not affected to any greater extent by sludge applications than were those in drainage water from Blount and Elliott silt loam soils.

Log-normal distribution plots for levels of several water quality parameters measured in runoff and drainage waters from Blount silt loam, Elliott silt loam and Plainfield loamy and, with and without sludge, are shown in Figures 2 through 85. The majority of the measurements were made on water samples collected over a 6 year period between 1971 and 1977, where an annual collection period was May 1 to April 30. But concentrations of Ni, Cr, Pb, Se, As, Sb, and Hg in water samples were determined only from composited samples in the 1976 to 1977 year.

The distribution of concentrations or levels for several of the water quality parameters lie relatively close to a straight line and thus are best described by the geometric mean and geometric standard deviation. But from an examination of graphs for K, it appears that for this element two log-normally distributed populations are exhibited. Although no effort has yet been made to analyze the data for two log-normal populations, there are several reasons why such a situation might exist. In some years, after the soil has undergone extensive freezing and thawing, K may be liberated from soil minerals in quantities that cause higher concentrations in runoff and drainage waters collected during the spring months. Potassium fertilizer was applied each year, so some portion of it may have been readily leached and transported from the soil surface by runoff water. Periodically recurring high losses of K may have been caused by sludge-borne NH_4^+ ions simply displacing K from exchange positions on and in soil minerals.

As shown by the geometric standard deviations (Tables 3 and 4), the data were high variable. This is to be expected since the frequency, duration, and intensity of rainstorms would determine total amounts of material eroded from soil surfaces as well as the direct dilution of concentrations in runoff water. Geometric standard deviations for drainage water data were about as expected. The cycling between high and low concentrations is illustrated by Figure 86, where concentrations of NO_3-N in drainage water samples were plotted against cumulative discharge volumes that

(continued on Page 134)

TABLE 5. GEOMETRIC MEAN LEVELS FOR WATER QUALITY PARAMETERS AS DETERMINED IN RUNOFF WATER SAMPLES COLLECTED FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS DURING THE PERIOD 1971-1977 (MEASURED FROM MAY 1 OF THE YEAR TO APRIL 30 OF THE FOLLOWING YEAR.a/b/

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
Total Solid (%)	71-72	0.06	0.07	0.05	0.05	0.05	0.06	0.10	0.07	0.05	0.13	0.04	0.04
	72-73	0.07	0.07	0.08	0.08	0.06	0.06	0.08	0.12	0.07	0.08	0.06	0.10*
	73-74	0.08	0.11	0.12	0.07	0.06	0.06	0.11	0.13	0.08	0.06	0.05	0.32**
	74-75	0.12	0.09	---	---	0.12	0.10	0.12	0.17	0.15	0.13	---	0.20
	75-76	0.10	0.08	---	---	0.09	0.06	0.14	0.26	0.12	0.06	---	0.06
	76-77	0.04	0.05	---	---	0.04	0.03	0.02	0.04	0.03	0.08	---	0.03
Org-C	72-73	0.29	---	0.26	---	---	---	0.63	---	0.20	---	---	0.42
	73-74	---	---	---	---	---	---	---	---	---	---	---	---
	74-75	---	---	---	---	---	---	---	---	---	---	---	---
	75-76	30.08	25.07	---	---	28.25	22.14	25.77	47.14*	23.98	21.21	---	16.03
	76-77	---	---	---	---	---	---	29.75	37.71	---	---	---	---
EC mmho/cm	71-72	0.33	0.52**	0.21	0.31**	0.27	0.45**	0.23	0.20	0.50	0.34	0.17	0.25*
	72-73	0.25	0.37**	0.22	0.36**	0.23	0.29	0.22	0.19	0.20	0.17	0.17	0.17
	73-74	0.30	0.40**	0.30	0.40*	0.33	0.38	0.24	0.24	0.30	0.22	0.22	0.19
	74-75	0.24	0.35**	0.24	0.28	0.23	0.16	0.21	0.19	0.19	0.23	0.27	0.27
	75-76	0.17	0.35**	---	---	0.20	0.24	0.20	0.20	0.23	0.35	---	0.16
	76-77	0.31	0.51	---	---	0.28	0.36	0.25	0.43	0.18	0.84	---	0.18
pH (units)	71-72	7.4	7.3	7.4	7.2*	7.3	7.0	7.2	6.9	7.2	7.1	7.1	7.3
	72-73	7.6	7.5	7.5	7.5	7.3	7.2	7.5	7.2*	7.4	7.5	7.4	7.5
	73-74	7.6	7.5	7.5	7.4	---	---	7.5	7.0**	7.3	7.3	6.9	7.6
NO_3-N	71-72	7.2	10.6*	3.3	7.3**	7.1	17.1**	5.5	3.5	17.3	10.3	4.7	5.1
	72-73	4.1	9.4**	3.3	9.2**	4.5	12.2**	3.5	4.3	3.8	3.7	4.1	2.2**
	73-74	6.4	13.6**	4.7	13.6**	8.3	16.0**	4.7	5.0	6.6	6.1	6.4	2.5**
	74-75	4.1	10.8**	---	---	4.6	3.0	5.1	4.4	2.5	4.8	---	3.0
	75-76	1.9	11.8**	---	---	3.0	6.4*	2.7	3.1	4.5	14.9*	---	3.6
	76-77	13.1	26.9	---	---	11.6	15.9	8.0	22.3*	6.6	---	---	7.6
NH_4-N	72-73	0.29	0.37	0.40	0.51	0.50	0.67	0.40	1.21**	0.39	0.34	0.87	0.69
	73-74	0.41	0.51	0.27	0.47	0.24	0.98	0.30	0.59*	0.31	0.79*	0.89	0.36
	74-75	---	---	---	---	---	---	0.57	0.38	---	---	---	---

(continued)

TABLE 5. (continued)

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
P	71-72	1.017	1.86**	1.38	1.48	1.36	1.55	1.49	3.08*	1.77	1.95	1.23	1.83
	72-73	1.61	1.87	1.28	2.62**	1.35	1.45	1.23	1.99*	1.56	1.73	2.30	2.79
	73-74	1.03	1.28	1.17	1.36	0.86	1.16	1.18	1.34	1.05	1.18	1.61	3.00**
	74-75	1.84	2.71*	---	---	2.11	1.47	2.04	2.20	1.83	3.33	---	4.78
	75-76	1.42	1.79	---	---	0.99	1.26	1.78	2.94	1.39	1.90	---	1.05
	76-77	0.68	1.00	---	---	---	---	0.76	1.86*	---	---	---	---
K	71-72	18.10	30.35*	13.74	16.56	18.08	24.37	22.10	17.67	28.44	20.39	11.58	9.41
	72-73	7.04	12.48**	7.69	8.63	7.35	7.57	6.49	9.62*	7.50	8.83	9.17	10.11
	73-74	6.94	8.38*	8.42	7.63	8.07	4.85**	8.28	9.46	7.55	5.02**	6.42	11.99**
	74-75	10.45	11.02	---	---	11.12	8.35*	9.76	9.58	9.84	11.04	---	16.38
	75-76	10.22	13.37*	---	---	9.54	10.03	9.85	14.10*	11.69	16.25	---	12.66
	76-77	4.40	5.28	---	---	---	4.66	8.83	13.40	---	---	---	---
Na	71-72	6.70	8.72	3.98	5.60	9.24	7.88	6.24	3.52*	2.80	4.93	3.28	4.20
	72-73	5.59	6.82	3.95	5.88**	7.28	4.70**	5.22	2.64**	3.30	2.25*	3.00	3.54
	73-74	4.46	3.72	3.69	5.20	6.59	4.78	4.46	3.05	5.60	1.80**	2.35	2.88
	74-75	12.89	6.70*	1.84	1.40	11.16	3.09*	4.37	1.75	17.84	13.62	---	11.34
	75-76	4.44	3.55	---	---	5.15	5.81	2.85	2.77	3.44	6.84	---	1.15
	76-77	7.54	2.39	---	---	--	9.38	3.70	6.35	---	---	---	---
Fe	71-72	12.4	6.5*	12.9	5.7*	7.6	5.9	15.1	15.2	2.1	22.9**	7.2	5.1
	72-73	13.1	9.6	17.1	10.9	9.0	9.0	14.3	23.0	11.4	23.0	11.3	33.6*
	73-74	7.9	10.2	12.7	9.4	8.4	5.5	14.5	17.1	9.7	7.6	6.9	64.1**
	74-75	19.5	11.1	---	---	23.5	13.9	18.3	52.3	19.7	17.0	---	36.5
	75-76	11.1	5.4*	---	---	6.9	6.4	7.6	16.9	5.1	3.9	---	2.3
	76-77	2.4	1.1	---	---	1.2	1.1	1.5	1.6	2.1	0.2	---	3.8
Mn	71-72	0.24	0.13*	0.25	0.12	0.19	0.20	0.40	0.43	0.05	0.59**	0.17	0.10
	72-73	0.30	0.20	0.35	0.18**	0.22	0.25	0.22	0.52*	0.25	0.33	0.26	0.64*
	73-74	0.21	0.24	0.40	0.18	0.21	0.11	0.47	0.57	0.26	0.17	0.29	1.56**
	74-75	0.62	0.25*	---	---	0.71	0.59	0.59	0.88	0.62	0.46	---	0.86
	75-76	0.39	0.13**	---	---	0.26	0.17	0.31	0.58	0.17	0.09	---	0.07
	76-77	0.05	0.04	---	---	0.04	0.04	0.04	0.07	0.04	0.03	---	0.07

(continued)

TABLE 5. (continued)

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
Zn	71-72	0.08	0.12*	0.10	0.12	0.06	0.12*	0.15	0.34*	0.06	0.31**	0.09	0.18
	72-73	0.09	0.16**	0.12	0.21*	0.06	0.15**	0.09	0.34**	0.10	0.22**	0.13	0.44**
	73-74	0.05	0.14**	0.07	0.13	0.06	0.10	0.11	0.25*	0.08	0.10	0.09	0.63**
	74-75	0.12	0.18	---	---	0.14	0.21	0.17	0.38	0.17	0.31	---	0.67
	75-76	0.12	0.14	---	---	0.10	0.10	0.11	0.36**	0.12	0.12	---	0.06
	76-77	0.02	0.04	---	---	0.02	0.04	0.02	0.04	0.02	0.02	---	0.04
Cd	71-72	0.004	0.007	0.004	0.014**	0.003	0.007*	0.005	0.021*	0.003	0.027**	0.003	0.013
	72-73	0.01	0.02**	0.01	0.02**	0.01	0.02**	0.01	0.02**	0.01	0.01	0.005	0.02**
	73-74	0.004	0.01**	0.01	0.01	0.004	0.01	0.004	0.01**	0.005	0.003	0.01	0.02*
	74-75	0.006	0.01**	---	---	0.01	0.01	0.005	0.02**	0.01	0.02	---	0.02
	75-76	0.002	0.01**	---	---	0.003	0.004	0.003	0.011**	0.01	0.01	---	0.004
	76-77	0.001	0.002**	---	---	0.001	0.002	0.001	0.001	0.001	0.001	---	0.001
Cu	71-72	0.02	0.05**	0.03	0.04*	0.02	0.04**	0.03	0.08**	0.02	0.13**	0.02	0.06**
	72-73	0.03	0.07**	0.03	0.08**	0.02	0.05**	0.03	0.10**	0.02	0.07**	0.02	0.12**
	73-74	0.02	0.06**	0.03	0.05	0.03	0.04	0.04	0.08**	0.03	0.04	0.03	0.17**
	74-75	0.06	0.09*	---	---	0.06	0.06	0.05	0.15*	0.07	0.18	---	0.14
	75-76	0.04	0.06**	---	---	0.04	0.04	0.04	0.11**	0.04	0.07	---	0.02
	76-77	0.02	0.06**	---	---	0.01	0.02	0.01	0.07	0.01	0.07	---	0.03

a/ Results are reported as ppm unless otherwise noted.

b/ Water samples were collected from fertilized and irrigated control or check plots, 1, and maximum-sludge-treated plots, 4, in either a north, N, or south, S, series of plots.

*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

--- Insufficient data.

TABLE 6. GEOMETRIC MEAN LEVELS FOR WATER QUALITY PARAMETERS AS DETERMINED IN DRAINAGE SAMPLES COLLECTED FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS DURING THE PERIOD 1971-1977 (MEASURED FROM MAY 1 OF THE YEAR TO APRIL 30 OF THE FOLLOWING YEAR.a/b/

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
Total Solid (%)	71-72	0.12	0.23**	0.10	0.15**	0.06	0.31**	0.08	0.18**	0.06	0.13**	0.05	0.14**
	72-73	0.11	0.19**	0.10	0.18**	0.07	0.22**	0.08	0.15**	0.06	0.08**	0.06	0.10**
	73-74	0.07	0.18**	0.09	0.14**	0.07	0.18**	0.07	0.13**	0.05	0.08**	0.05	0.11**
	74-75	0.10	0.20**	0.12	0.13	0.08	0.19**	0.08	0.18**	0.06	0.09*	0.11	0.09
	75-76	0.09	0.22**	---	0.07	0.06	0.23**	0.07	0.22**	0.06	0.07	---	0.09
	76-77	0.09	0.23**	---	0.08	0.07	0.17	0.06	0.19	0.05	0.08	---	0.07
Org-C	72-73	---	1.06	---	1.04	---	1.49	0.67	1.48	0.72	---	0.58	0.85
	73-74	---	---	---	---	---	---	---	---	---	---	---	---
	74-75	8.38	15.63	---	9.44	8.08	17.86	8.76	19.44	11.28	8.48	---	13.42
	75-76	11.27	26.95**	---	10.99	9.08	28.10*	12.80	22.57**	7.67	11.01	---	8.41
	76-77	---	---	---	---	---	---	---	41.41	---	---	---	---
EC mmho/cm	71-72	1.49	2.92**	1.31	1.91**	0.82	3.64**	1.04	2.50**	0.62	1.63**	0.60	1.67**
	72-73	1.32	2.27**	1.30	2.37**	0.92	2.47**	1.09	1.70**	0.80	1.15**	0.72	1.32**
	73-74	0.85	2.07**	1.02	1.83**	0.95	2.24**	0.80	1.45**	0.65	0.99**	0.62	1.23**
	74-75	0.95	2.03**	0.93	1.28*	0.90	1.73**	0.87	1.43**	0.64	0.91**	0.61	1.10**
	75-76	0.78	2.29**	---	0.80	0.63	2.26**	0.59	1.87**	0.58	0.83**	---	1.21
	76-77	0.92	2.31**	---	0.84	0.87	1.99	0.68	1.24	0.49	0.62	---	0.68
pH (units)	71-72	8.1	7.8**	8.1	8.0	8.1	7.5**	8.2	7.8**	---	---	7.8	8.1
	72-73	7.9	7.8	7.8	7.8	7.9	7.8	8.0	7.8*	8.1	7.9	7.8	7.9
	73-74	8.0	7.7**	7.5	8.1**	8.0	7.9	8.1	7.6**	---	---	7.9	8.1
NO_3-N	71-72	96.6	200.9**	67.4	104.6*	30.5	289.0**	46.2	159.1**	14.9	125.5**	24.7	90.3**
	72-73	42.0	149.1**	49.1	155.0**	16.7	181.2**	29.9	130.9**	18.3	59.8**	21.8	90.5**
	73-74	19.3	125.2**	24.6	103.7**	19.8	146.9**	17.0	79.4**	17.5	39.0**	17.8	66.4**
	74-75	37.4	137.7**	39.5	65.8*	28.2	120.6**	26.6	98.2**	23.6	43.1**	21.1	55.6**
	75-76	29.7	157.1**	---	23.8	13.1	180.9**	15.6	143.8**	31.0	39.7	---	83.2
	76-77	39.2	151.7**	---	24.0	24.8	164.0	21.1	147.7**	18.8	23.1	---	29.8
NH_4-N	72-73	0.07	0.16**	0.03	0.06	0.03	0.15**	0.03	0.10	---	---	0.03	0.04
	73-74	0.06	0.19**	0.05	0.07**	0.06	0.13**	0.07	0.08	0.05	0.05	0.05	0.05
	74-75	0.24	0.12*	0.57	0.12**	0.30	0.24	---	---	0.06	0.06	0.10	0.09

(continued)

TABLE 6. (continued)

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
P	71-72	0.14	0.46**	0.40	0.43	0.68	1.78**	0.33	0.64	---	---	0.38	0.16*
	72-73	0.27	0.42*	0.09	0.23**	0.31	0.74**	0.18	0.28	0.43	0.29*	0.40	0.36
	73-74	0.18	0.29**	0.10	0.09	0.24	0.67**	0.15	0.36**	0.33	0.31	0.29	0.19**
	74-75	0.29	0.44	0.48	0.10*	0.34	1.16**	0.27	0.55*	0.48	0.57	0.47	0.19**
	75-76	0.37	0.43	---	0.16	0.53	0.92**	0.44	0.41	0.98	0.60**	---	0.29
K	71-72	9.23	19.93**	3.43	6.34	7.97	26.87**	5.16	15.60**	---	---	10.44	12.94*
	72-73	4.81	8.23**	3.13	3.88	4.09	8.18**	2.60	3.90*	8.34	13.44**	8.51	13.71**
	73-74	2.55	3.66**	1.25	1.22	3.10	3.71*	1.85	2.61**	4.99	13.24**	4.07	9.27**
	74-75	3.57	5.18**	3.66	1.84**	5.07	6.21	2.29	4.63**	7.75	13.65**	7.48	13.79**
	75-76	3.58	5.06**	---	1.23	3.88	5.86**	2.97	5.30**	10.74	8.23	---	16.19
	76-77	5.64	7.45	---	1.31	5.81	8.79	2.54	4.22	10.07	9.00	---	10.06
Na	71-72	24.49	26.04	---	---	16.51	28.63**	5.54	16.72*	---	---	30.21	35.51
	72-73	35.24	35.64	26.08	26.37	29.12	41.57**	18.04	27.80**	49.61	17.40**	34.59	29.46
	73-74	14.43	28.75**	25.55	19.85*	21.80	35.56*	11.23	21.03**	25.90	16.44**	25.07	21.79
	74-75	33.50	42.21**	29.57	29.03	33.30	48.12*	17.75	39.84**	31.69	18.91**	30.25	15.86*
	75-76	36.68	42.59	---	16.67	28.53	52.56**	19.01	37.73**	48.78	18.36**	---	28.26
	76-77	34.46	44.55	---	15.82	22.31	36.32	15.43	25.43	32.40	9.17	---	14.44
Fe	71-72	0.5	0.3	0.2	0.2	0.3	2.0**	0.2	0.2	---	---	0.08	0.01**
	72-73	0.5	0.5	0.3	0.2	1.0	0.4**	0.3	0.5	0.3	0.5	0.3	0.2
	73-74	0.7	0.4**	0.3	0.1**	0.4	0.4	0.4	0.3	0.5	0.1**	1.8	0.2**
	74-75	1.4	0.6*	1.1	0.6	0.7	1.6	0.7	0.7	0.5	0.4	---	0.2
	75-76	1.4	0.6**	---	0.3	1.3	1.0	1.0	0.9	1.3	0.8	---	0.7
	76-77	0.8	0.4	---	0.2	0.4	0.2	0.4	1.3	0.7	0.6	---	1.6
Mn	71-72	0.014	0.009	0.014	0.018	0.008	0.030**	0.010	0.019	---	---	0.021	0.003**
	72-73	0.02	0.02	0.01	0.02*	0.01	0.05**	0.01	0.02*	0.01	0.01	0.02	0.005**
	73-74	0.03	0.02**	0.02	0.02	0.01	0.02**	0.03	0.02	0.02	0.01**	0.05	0.01**
	74-75	0.04	0.02	0.02	0.02	0.02	0.05**	0.02	0.02	0.02	0.01	0.09	0.01**
	75-76	0.04	0.02**	---	0.01	0.03	0.07**	0.04	0.06	0.04	0.03	---	0.03
	76-77	0.024	0.024	---	0.010	0.015	0.043	0.012	0.056	0.021	0.014	---	0.052

(continued)

TABLE 6. (continued)

Parameter	Year	Blount silt loam				Elliott silt loam				Plainfield loamy sand			
		S1	S4	N1	N4	S1	S4	N1	N4	S1	S4	N1	N4
Zn	71-72	0.019	0.037**	0.021	0.021	0.018	0.688**	0.015	0.040**	---	---	0.013	0.015
	72-73	0.02	0.04**	0.02	0.02	0.02	0.27**	0.01	0.02**	0.01	0.02*	0.02	0.02*
	73-74	0.02	0.03**	0.02	0.02	0.02	0.15**	0.01	0.05**	0.01	0.01	0.03	0.01**
	74-75	0.04	0.05*	0.03	0.03	0.03	0.16**	0.02	0.05**	0.02	0.03	0.05	0.03
	75-76	0.04	0.06**	---	0.03	0.03	0.23**	0.04	0.09**	0.04	0.04	---	0.04
	76-77	0.018	0.044**	---	0.018	0.016	0.205	0.014	0.048	0.015	0.023	---	0.048
Cd	71-72	0.003	0.006**	0.003	0.004	0.002	0.043**	0.002	0.005**	---	---	0.001	0.004**
	72-73	0.01	0.01	0.01	0.01	0.01	0.03**	0.01	0.01	0.003	0.01**	0.003	0.01**
	73-74	0.004	0.01**	0.004	0.005*	0.005	0.02**	0.003	0.01**	0.003	0.004	0.003	0.005**
	74-75	0.003	0.005**	0.004	0.004	0.003	0.01**	0.002	0.004**	0.002	0.003	0.005	0.003
	75-76	0.002	0.005**	---	0.001	0.002	0.01**	0.003	0.004	0.002	0.002	---	0.003
	76-77	0.001	0.002**	---	0.001	---	0.008	0.001	0.001	0.001	0.001	---	0.001
Cu	71-72	0.007	0.016**	0.004	0.007	0.007	0.074**	0.005	0.013**	---	---	0.004	0.007**
	72-73	0.01	0.03**	0.01	0.01*	0.01	0.04**	0.005	0.02**	0.005	0.01**	0.005	0.01**
	73-74	0.01	0.03**	0.01	0.01	0.01	0.04**	0.01	0.02**	0.01	0.02**	0.01	0.01
	74-75	0.01	0.03**	0.03	0.02	0.02	0.05**	0.01	0.03**	0.01	0.01	0.02	0.01
	75-76	0.02	0.03**	---	0.01	0.01	0.05**	0.02	0.03*	0.01	0.02**	---	0.02
	76-77	0.006	0.021**	---	0.008	0.010	0.047	0.008	0.016	0.006	0.008	---	0.011

a/ Results are reported as ppm unless otherwise noted.

b/ Water samples were collected from fertilized and irrigated control or check plots, 1, and maximum-sludge-treated plots, 4, in either a north, N, or south, S, series of plots adjacent to an instrument house.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

--- Insufficient data.

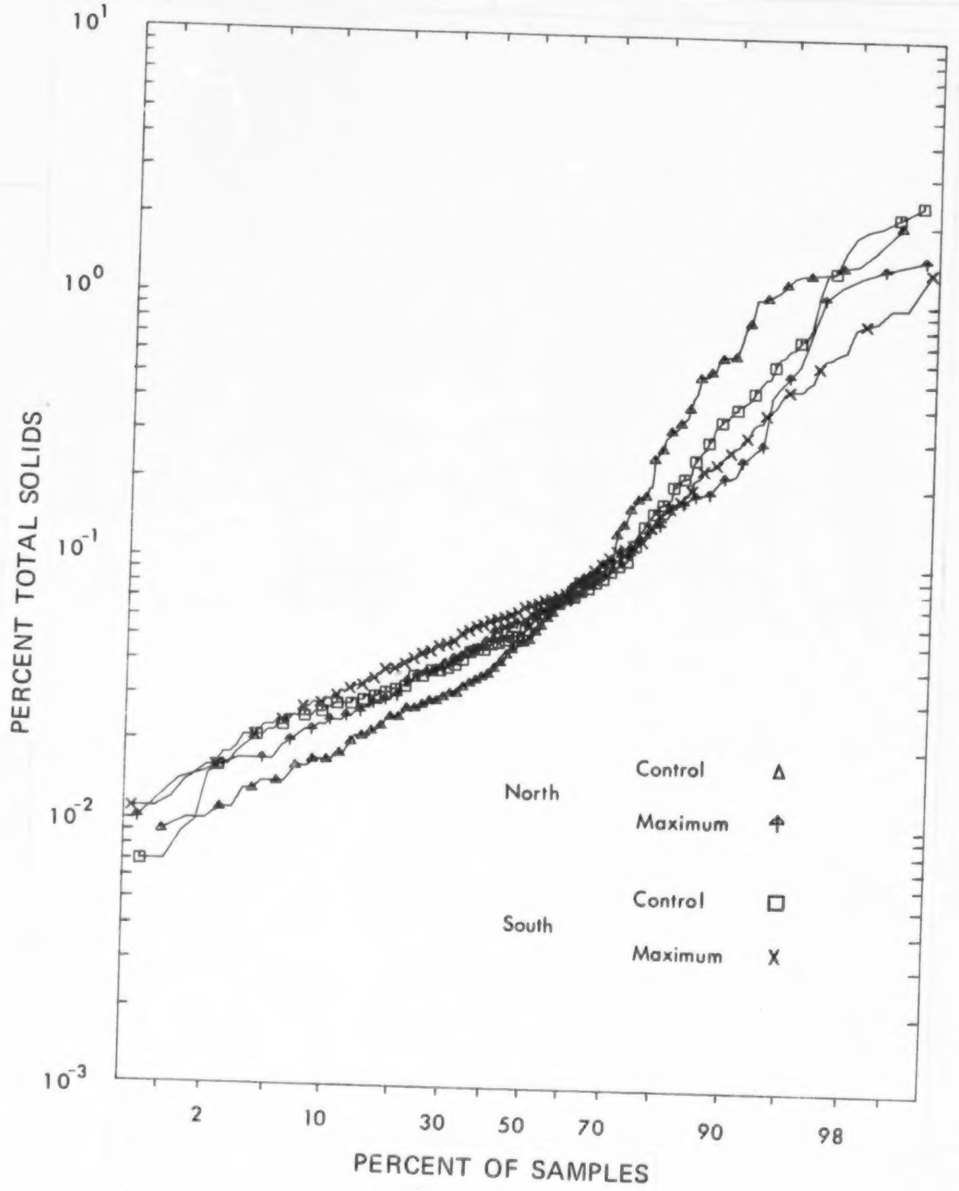

Figure 2. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distribution of total solids concentrations are percent of samples containing less than amounts shown on the vertical axis.

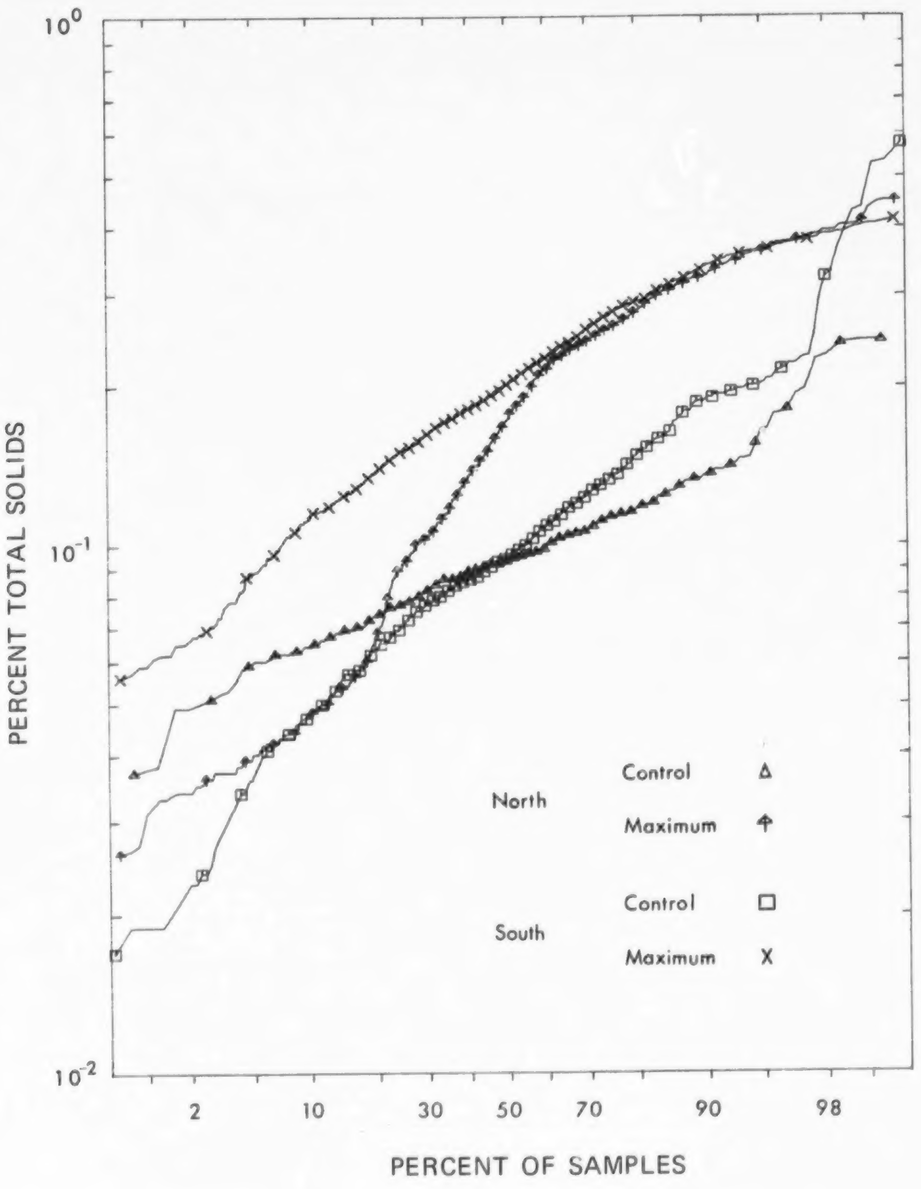

Figure 3. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of total solids concentrations are percent of samples containing less than amounts shown on the vertical axis.

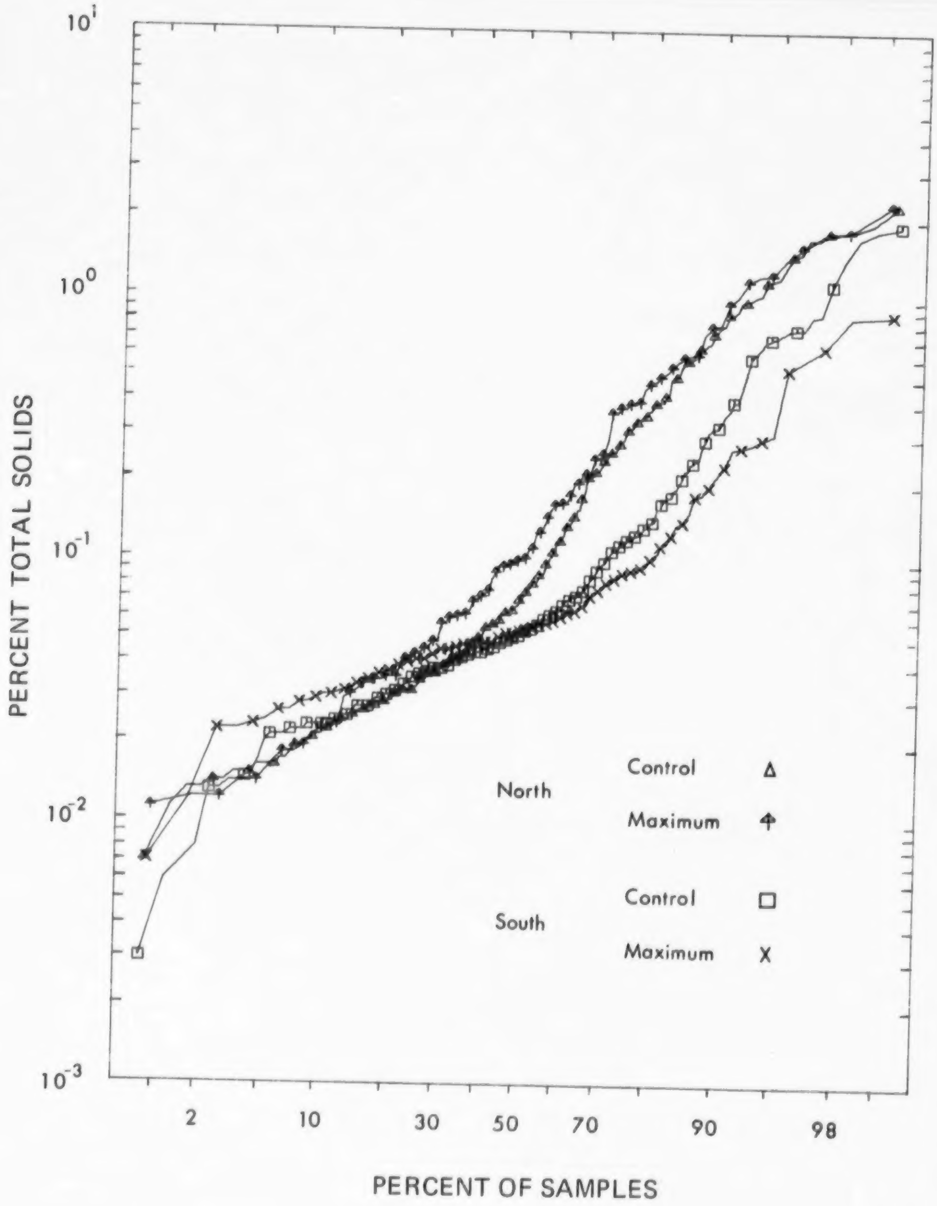

Figure 4. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distribution of total solids concentrations are percent of samples containing less than amounts shown on the vertical axis.

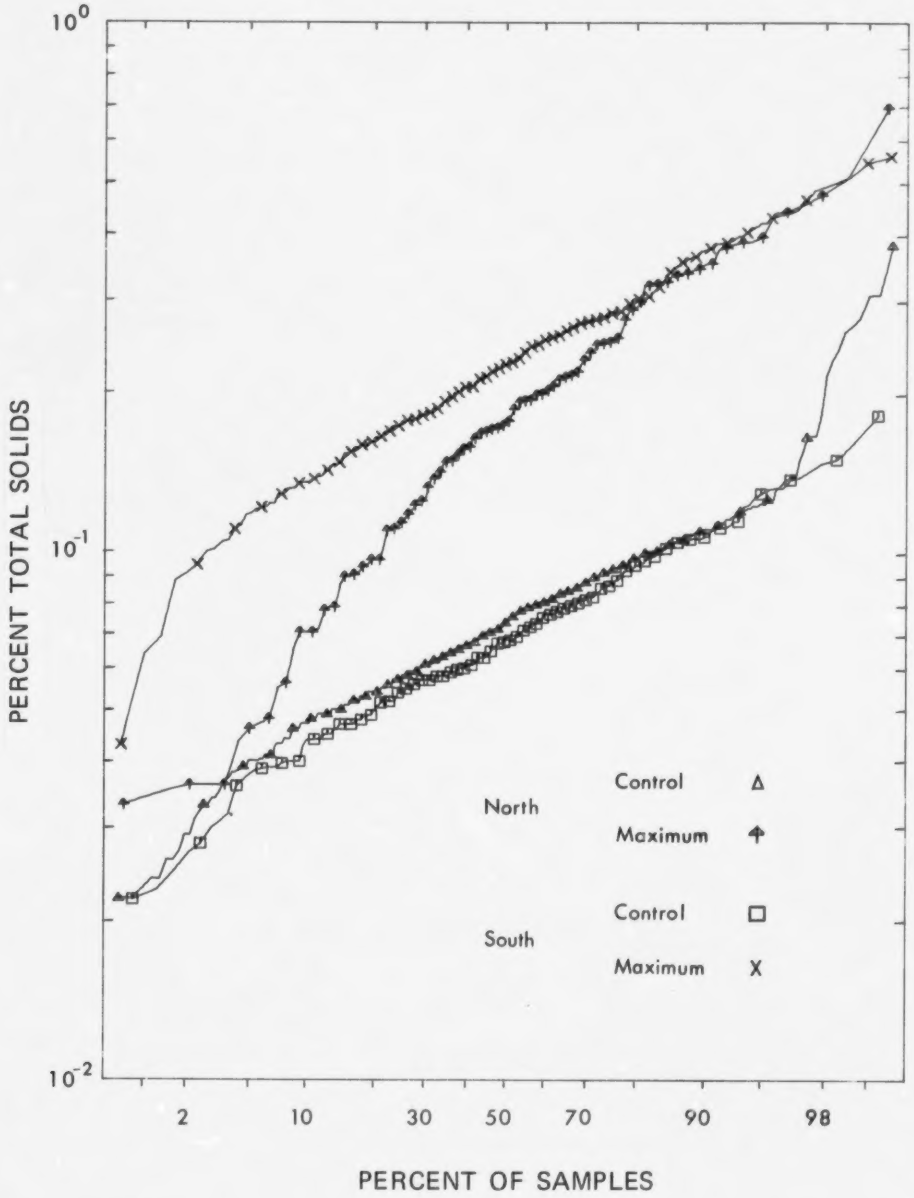

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Figure 5. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of total solids concentrations are percent of samples containing less than amounts shown on the vertical axis.

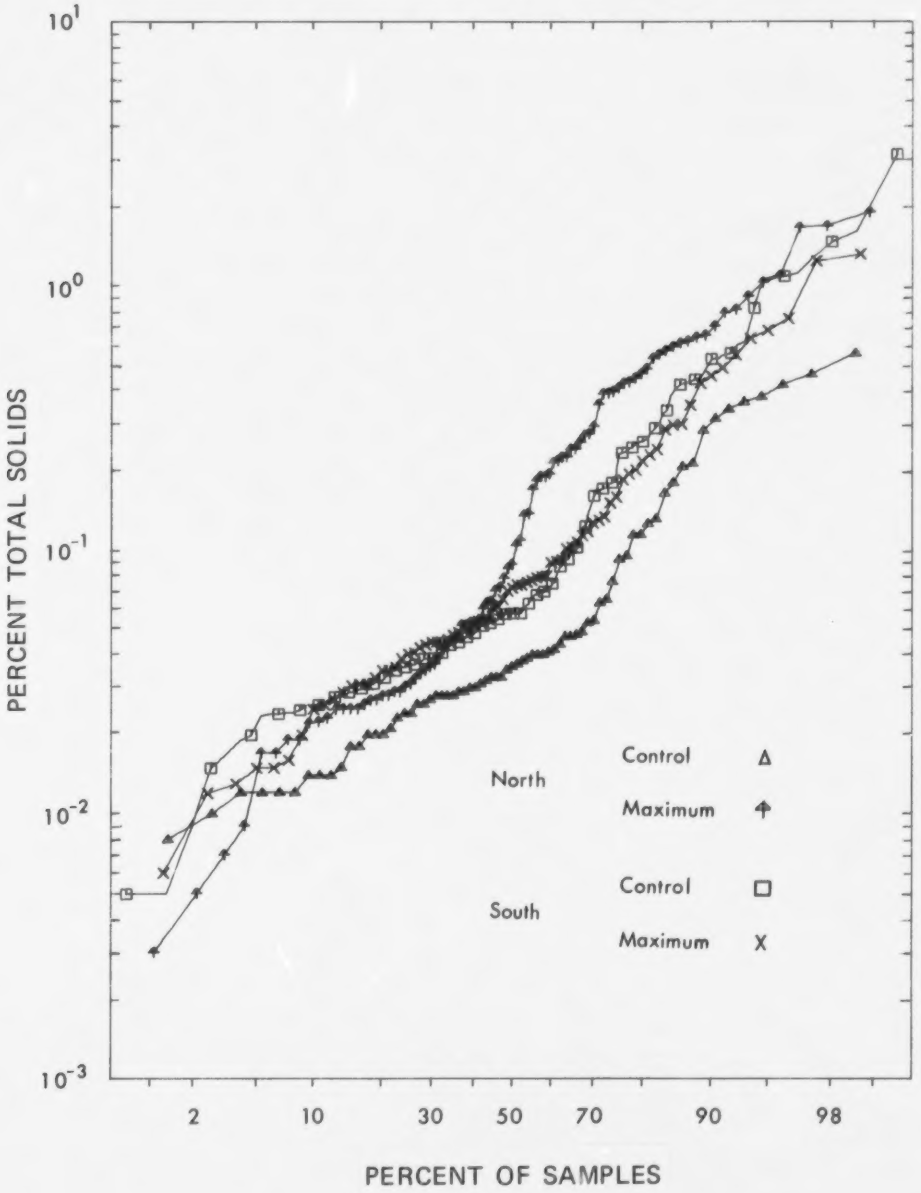

Figure 6. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of total solids concentrations are percent of samples containing less than amounts shown on the vertical axis.

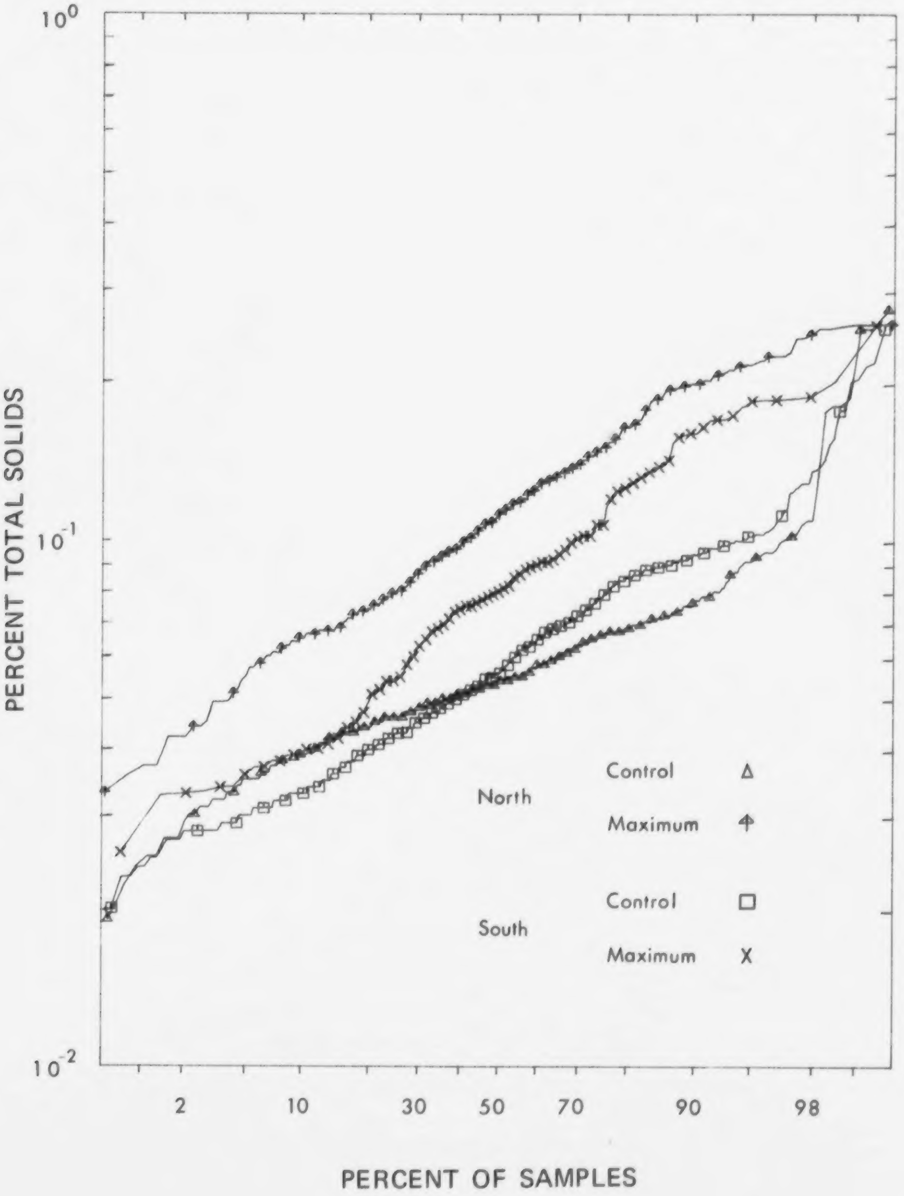

Figure 7. Frequency distribution of total solids concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of total solids concentrations are percent of samples containing less than amounts shwon on the vertical axis.

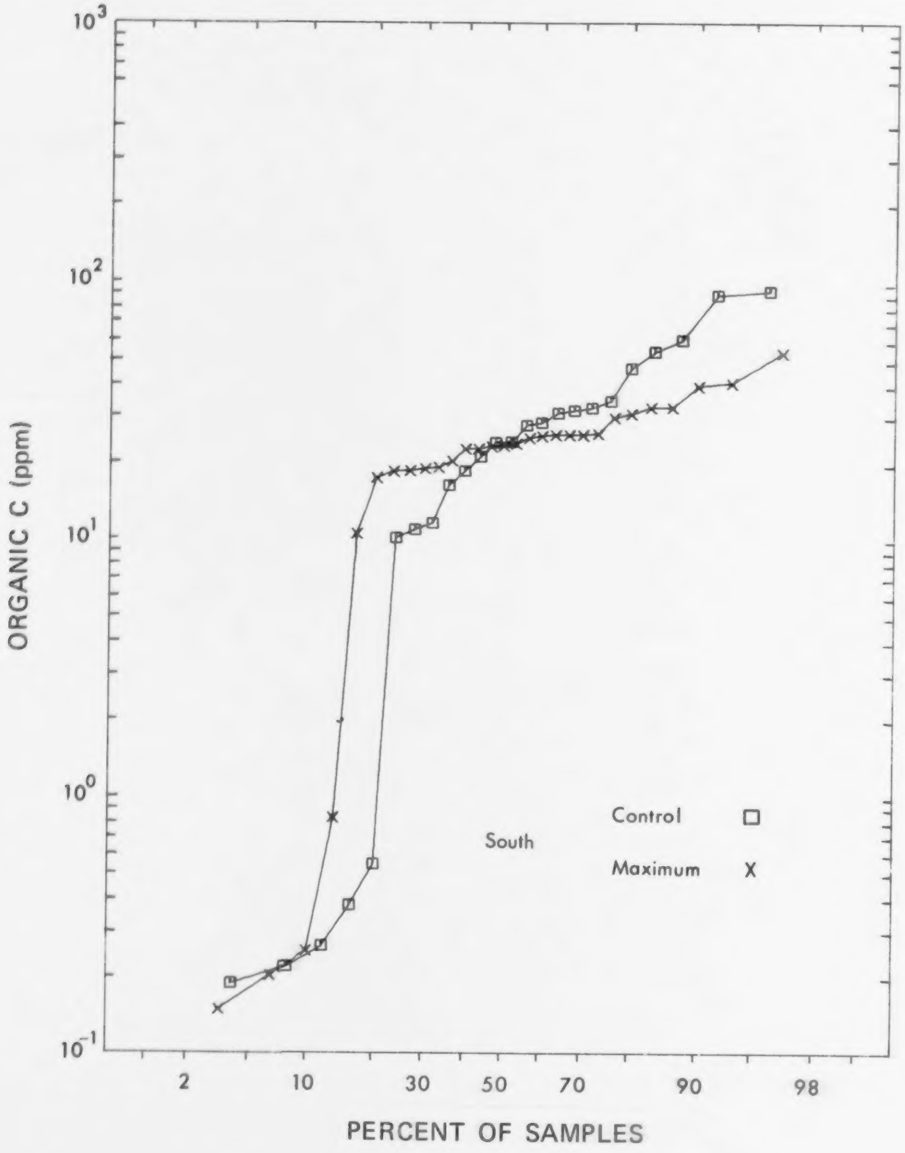

Figure 8. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

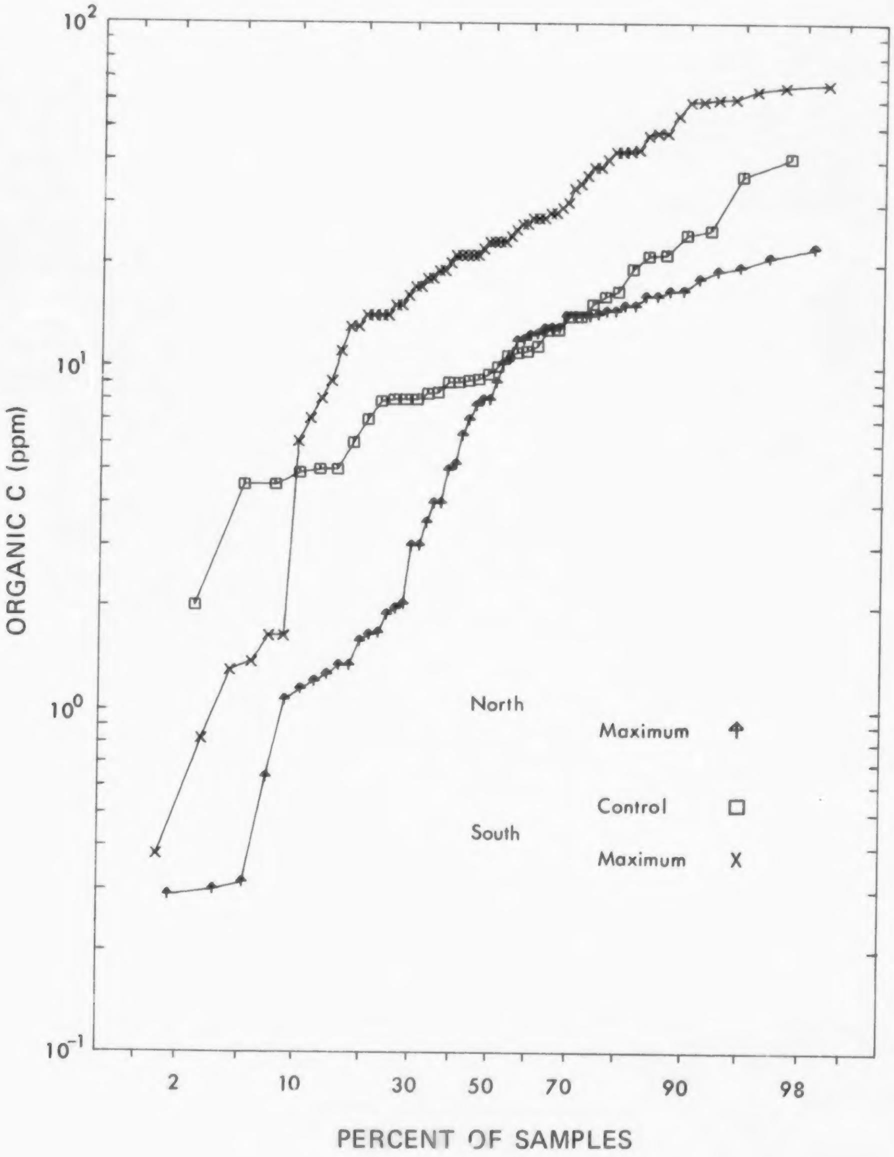

Figure 9. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

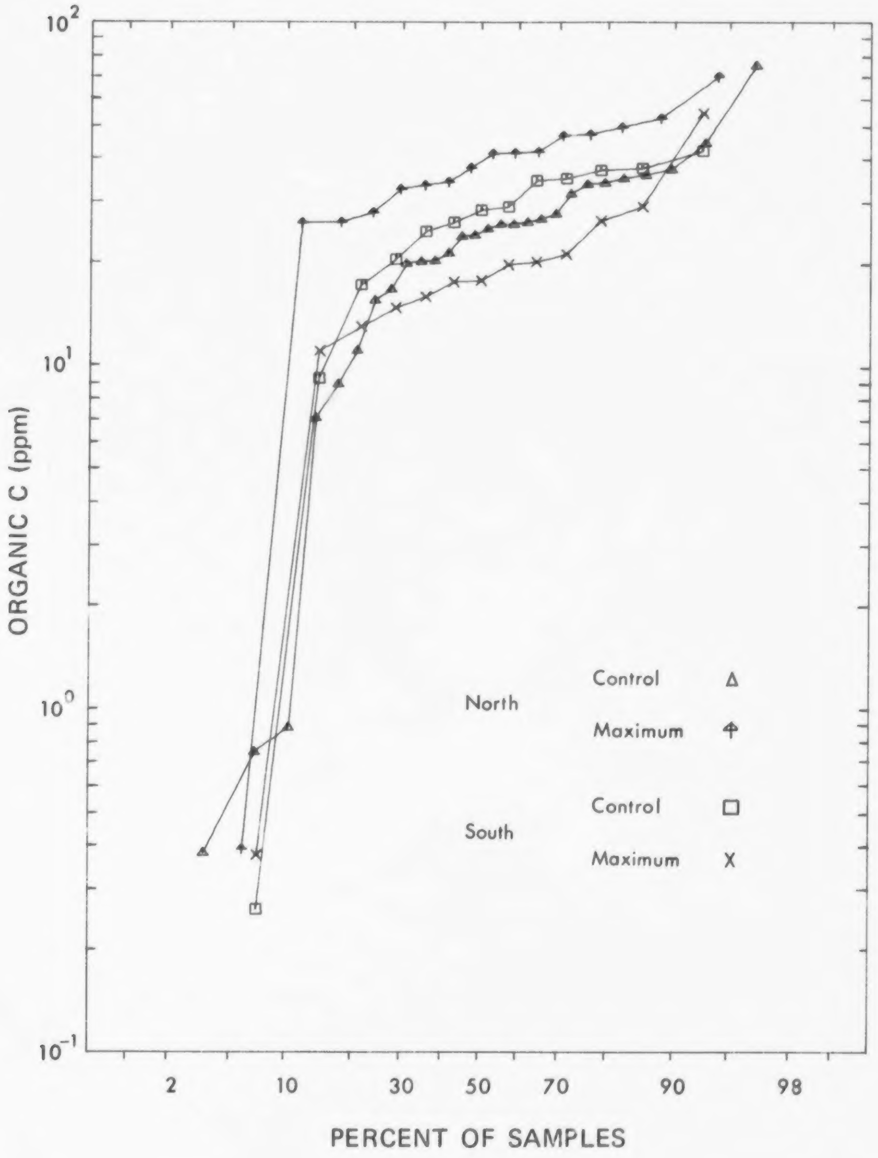

Figure 10. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

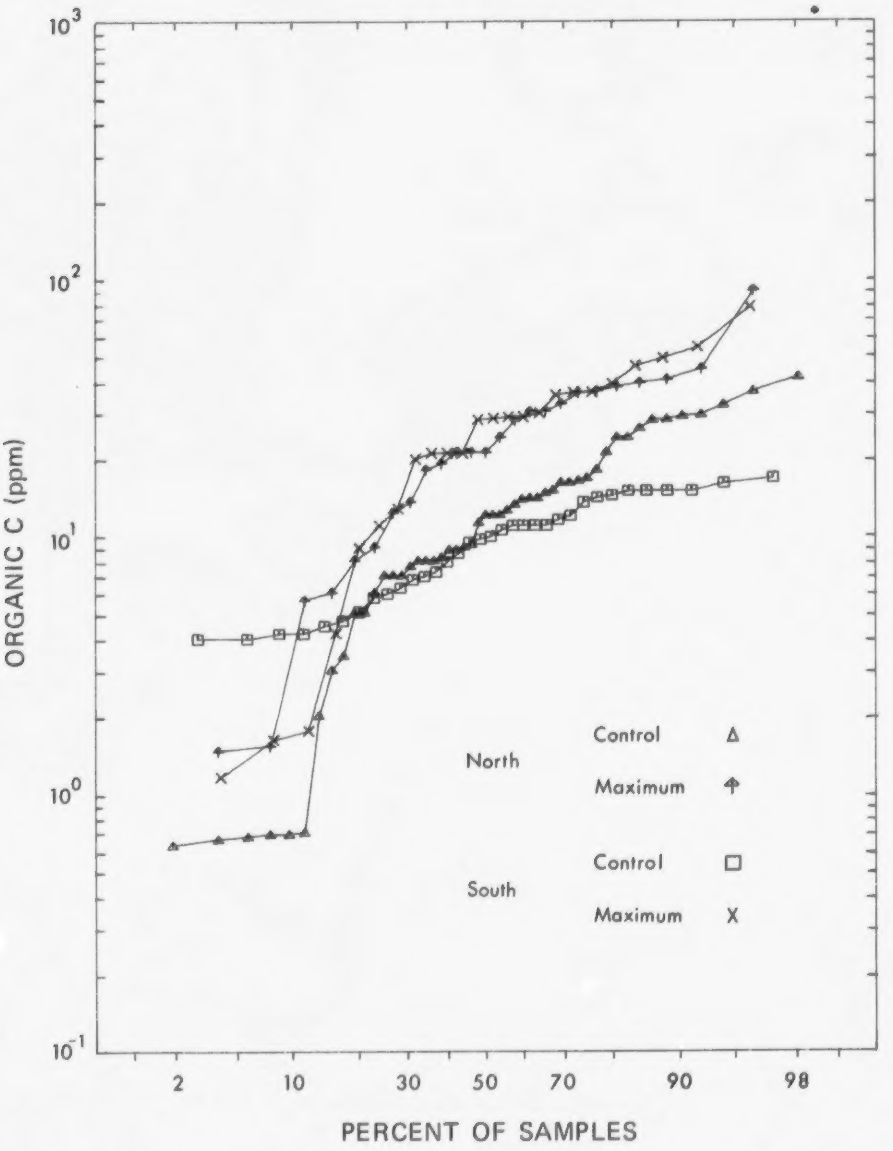

Figure 11. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

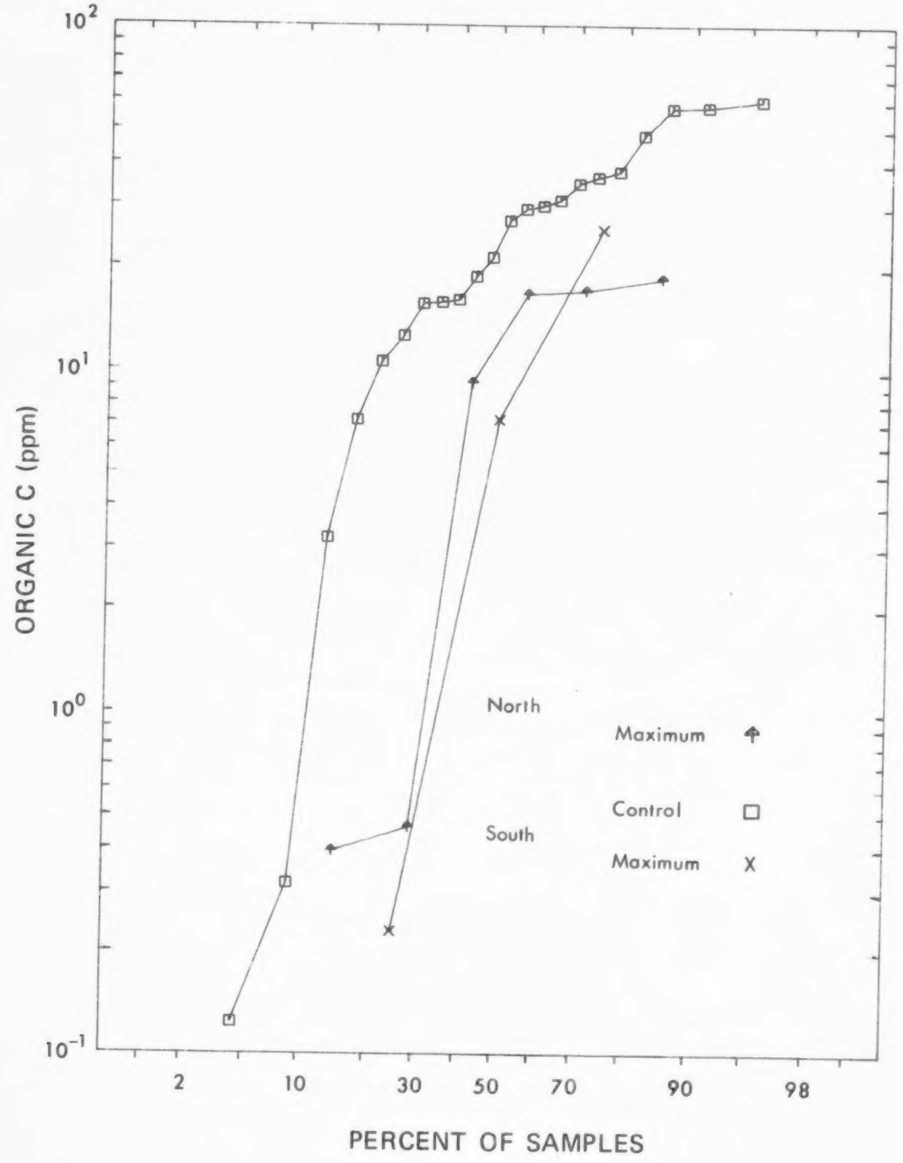

Figure 12. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

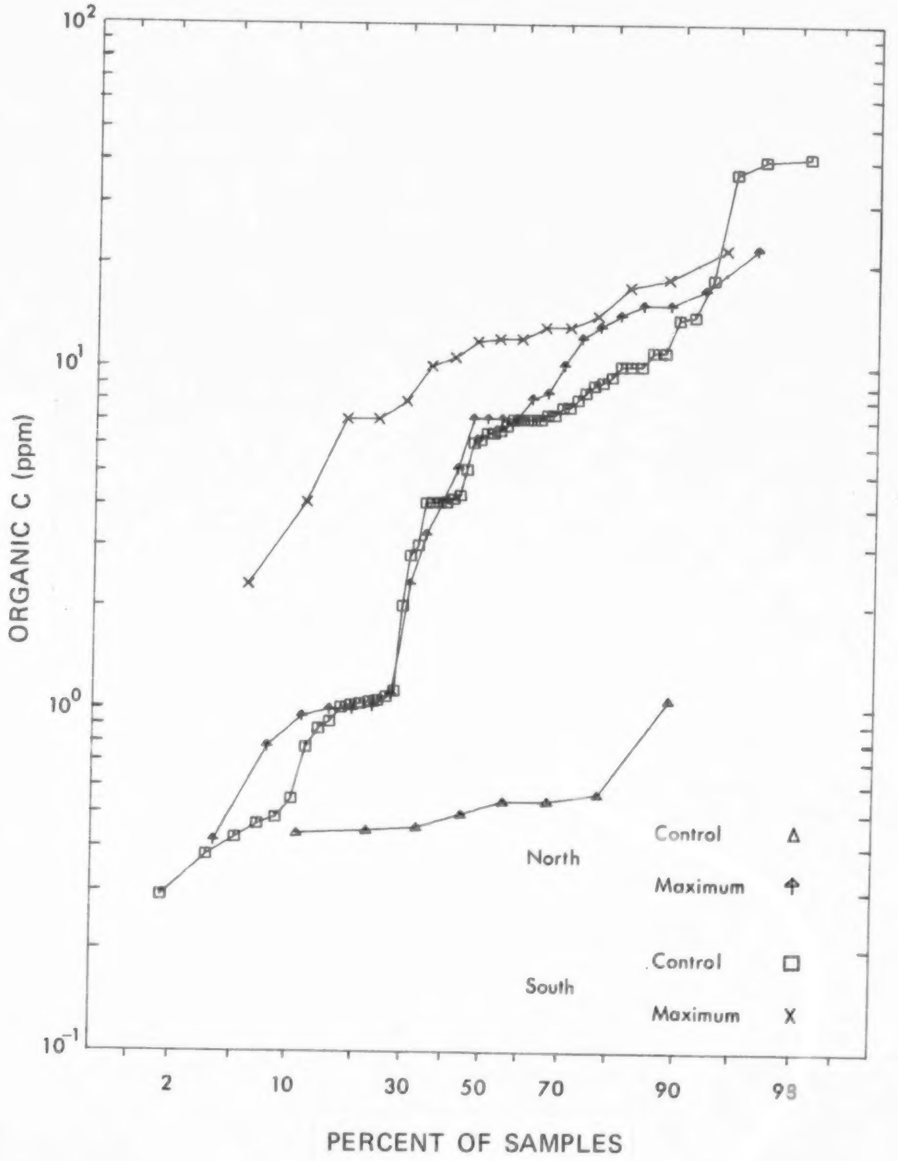

Figure 13. Frequency distribution of organic carbon (Org. C) concentrations during the period 5/1/72 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of organic carbon (Org. C) concentrations are percent of samples containing less than amounts shown on the vertical axis.

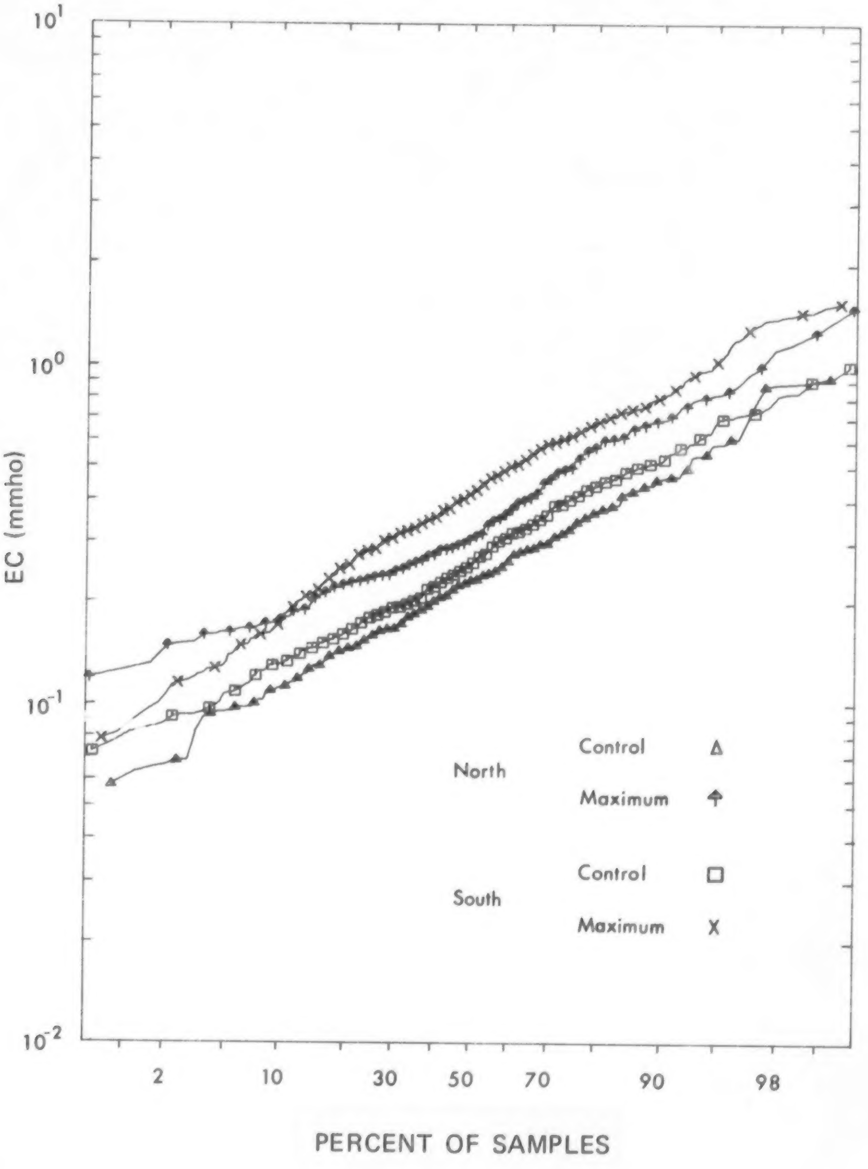

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Figure 14. Frequency distribution of conductivity during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

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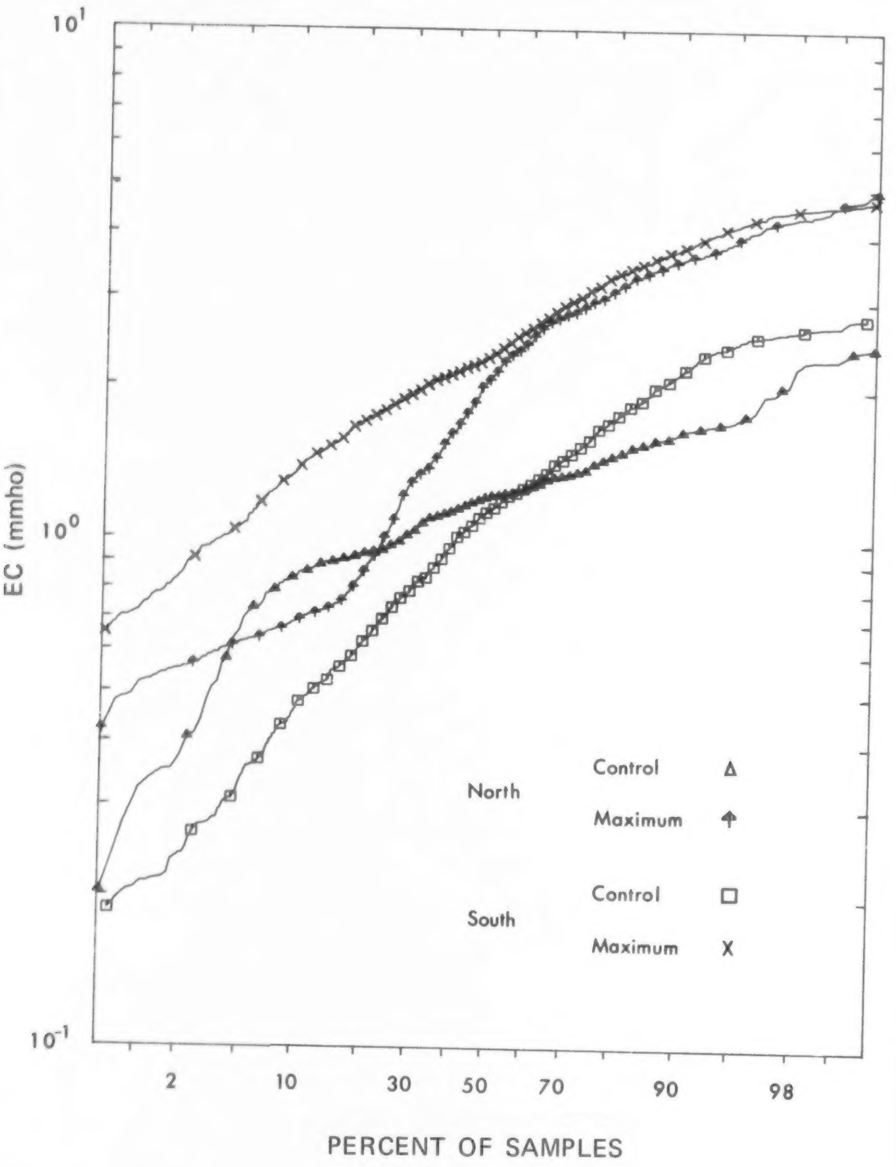

Figure 15. Frequency distribution of conductivity during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

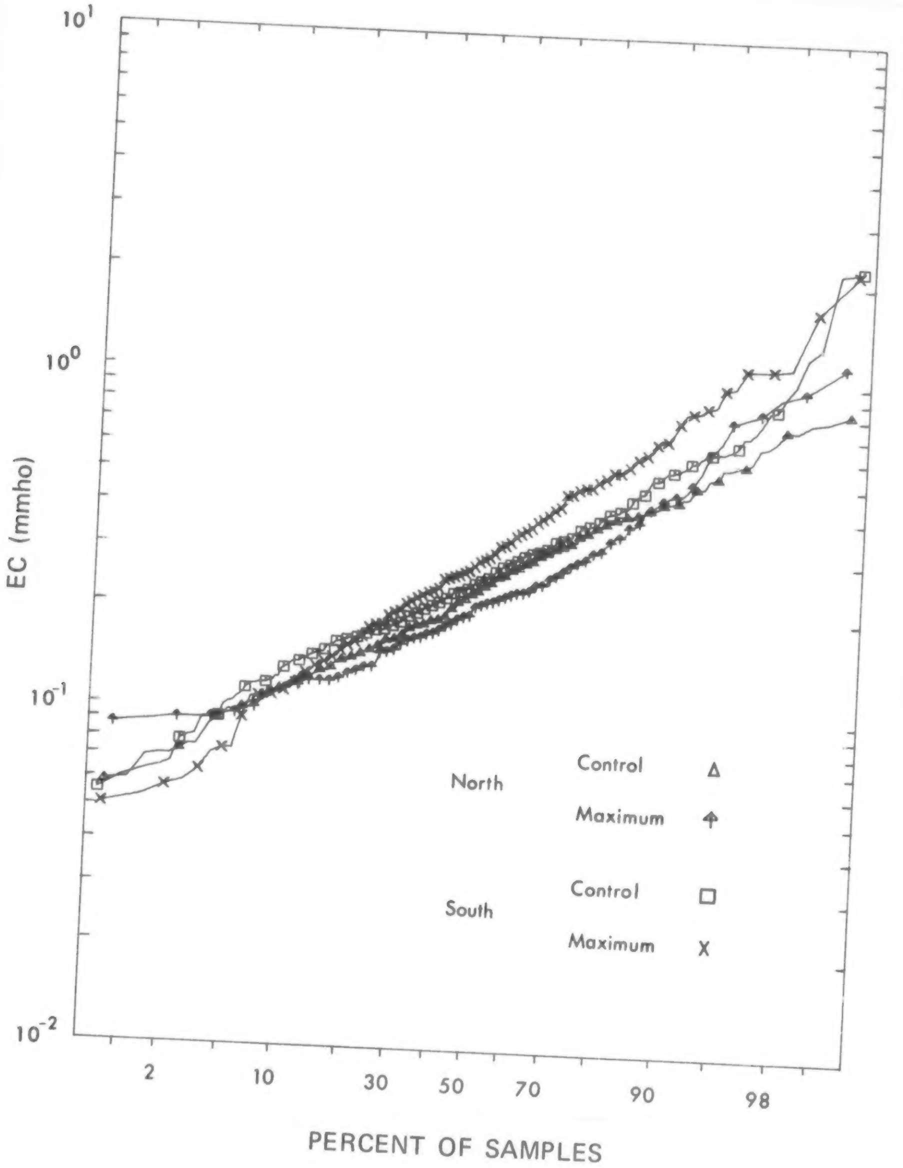

Figure 16. Frequency distribution of conductivity during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

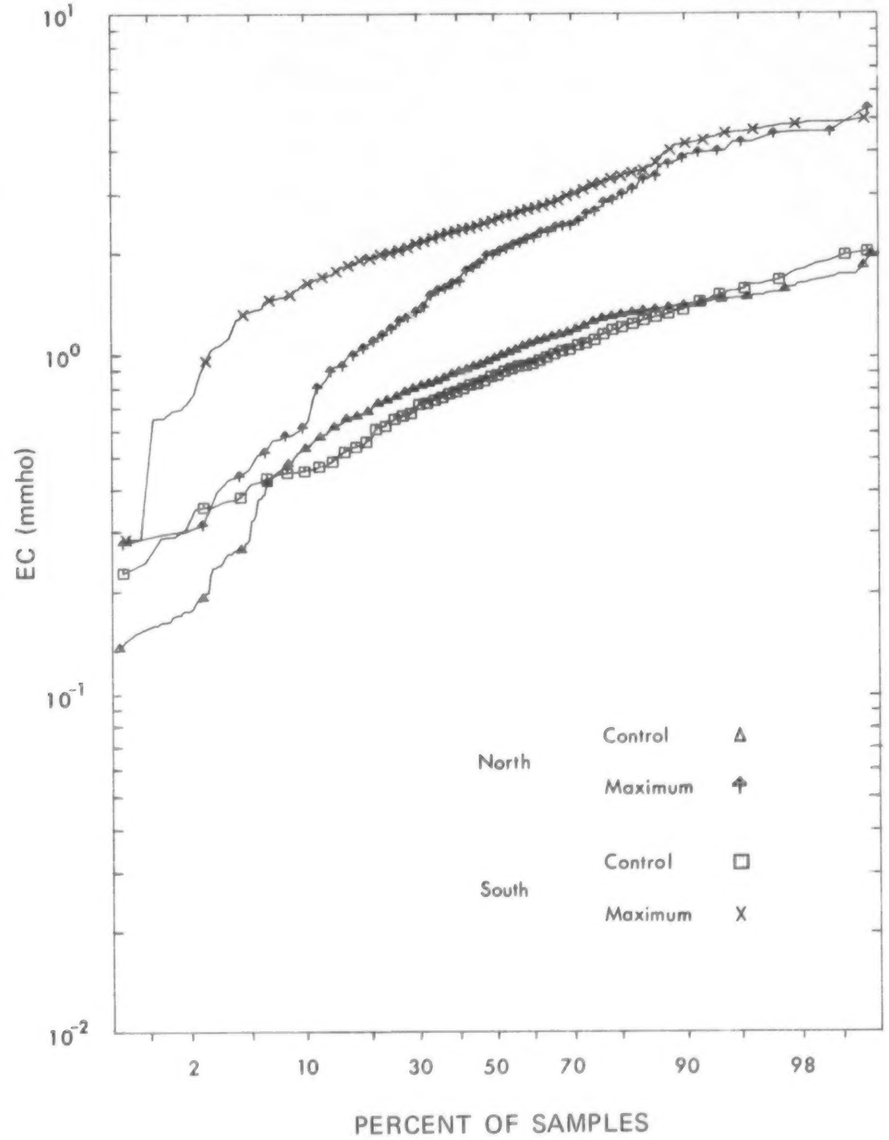

Figure 17. Frequency distribution of conductivity during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

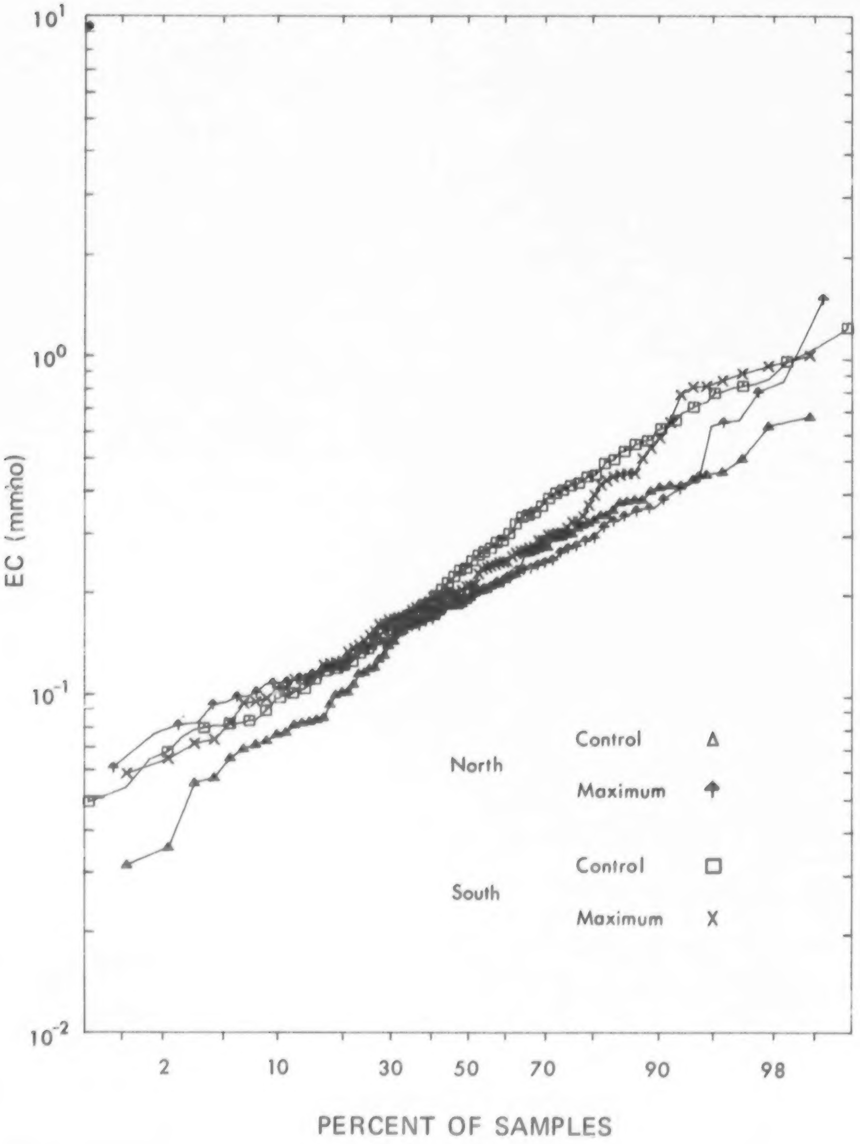

Figure 18. Frequency distribution of conductivity during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

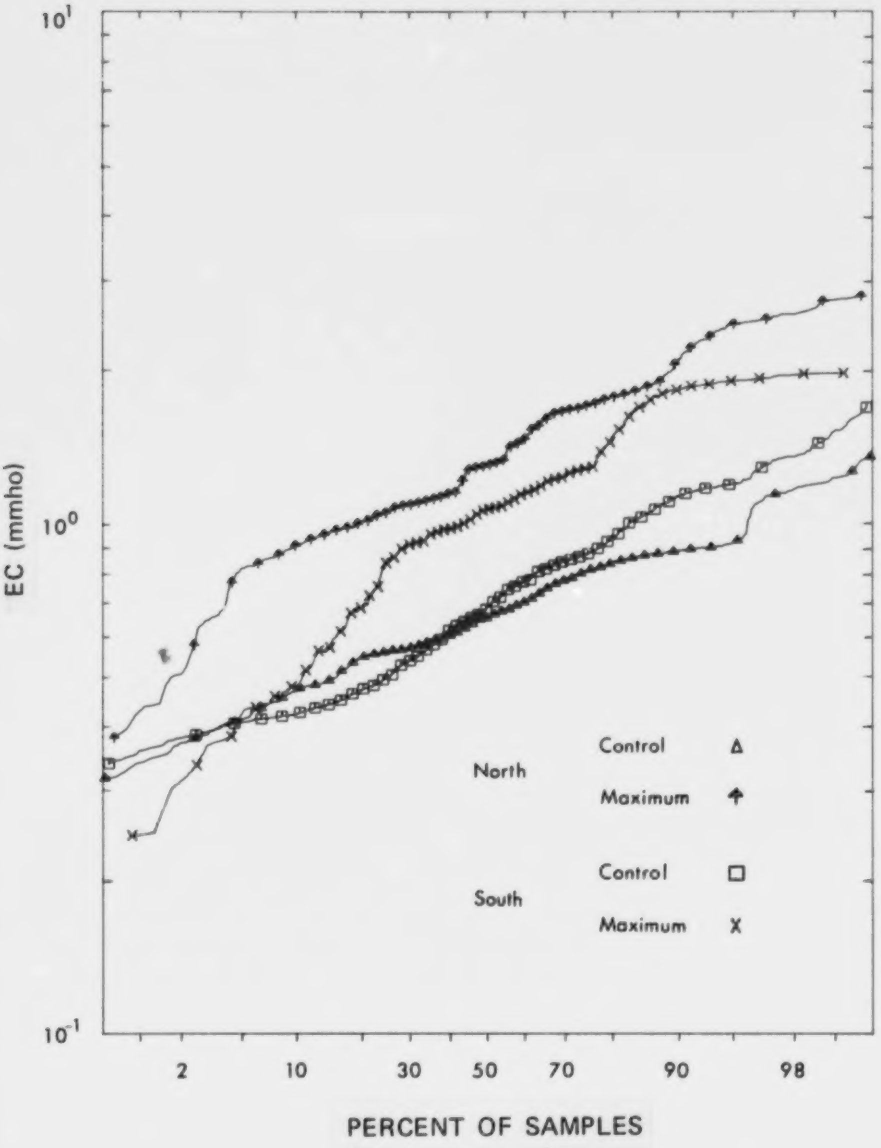

Figure 19. Frequency distributions of conductivity during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of conductivity are percent of samples containing less than amounts shown on the vertical axis.

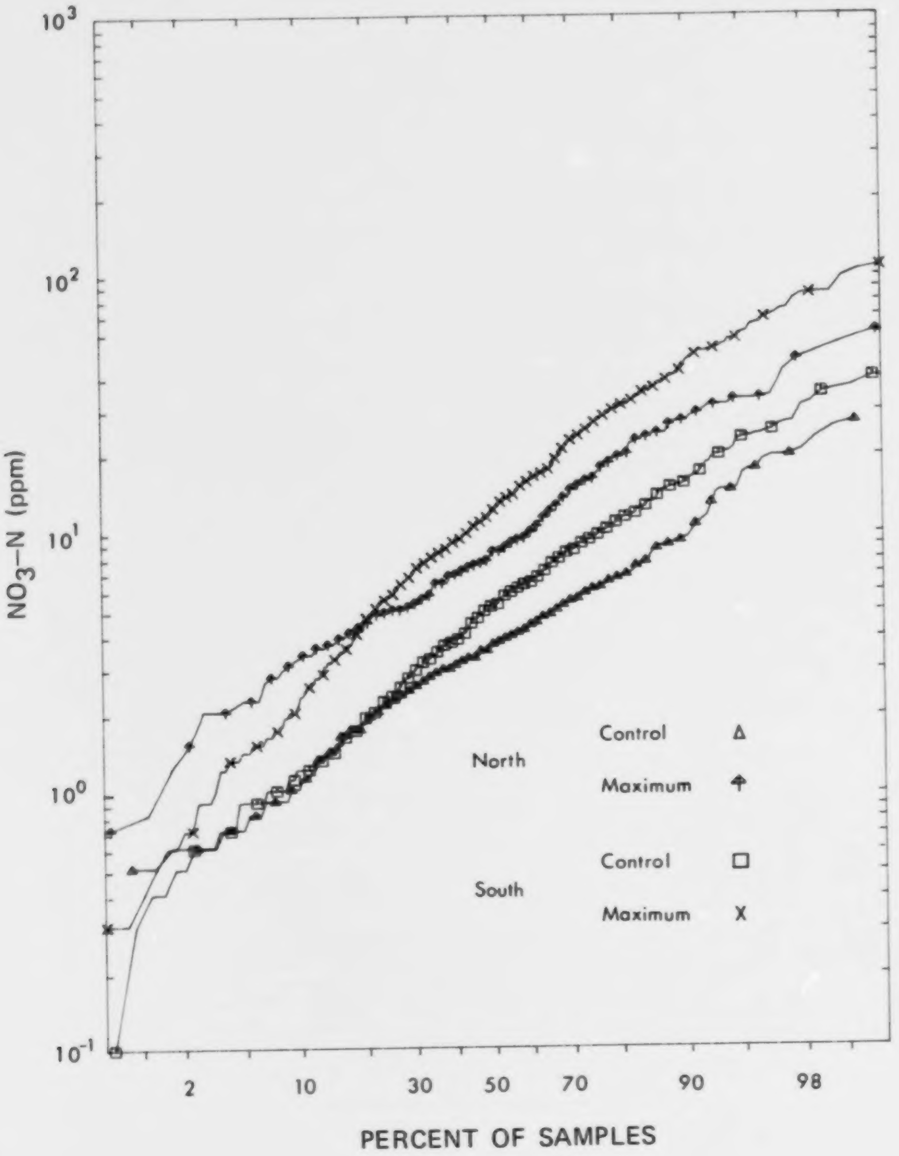

Figure 20. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

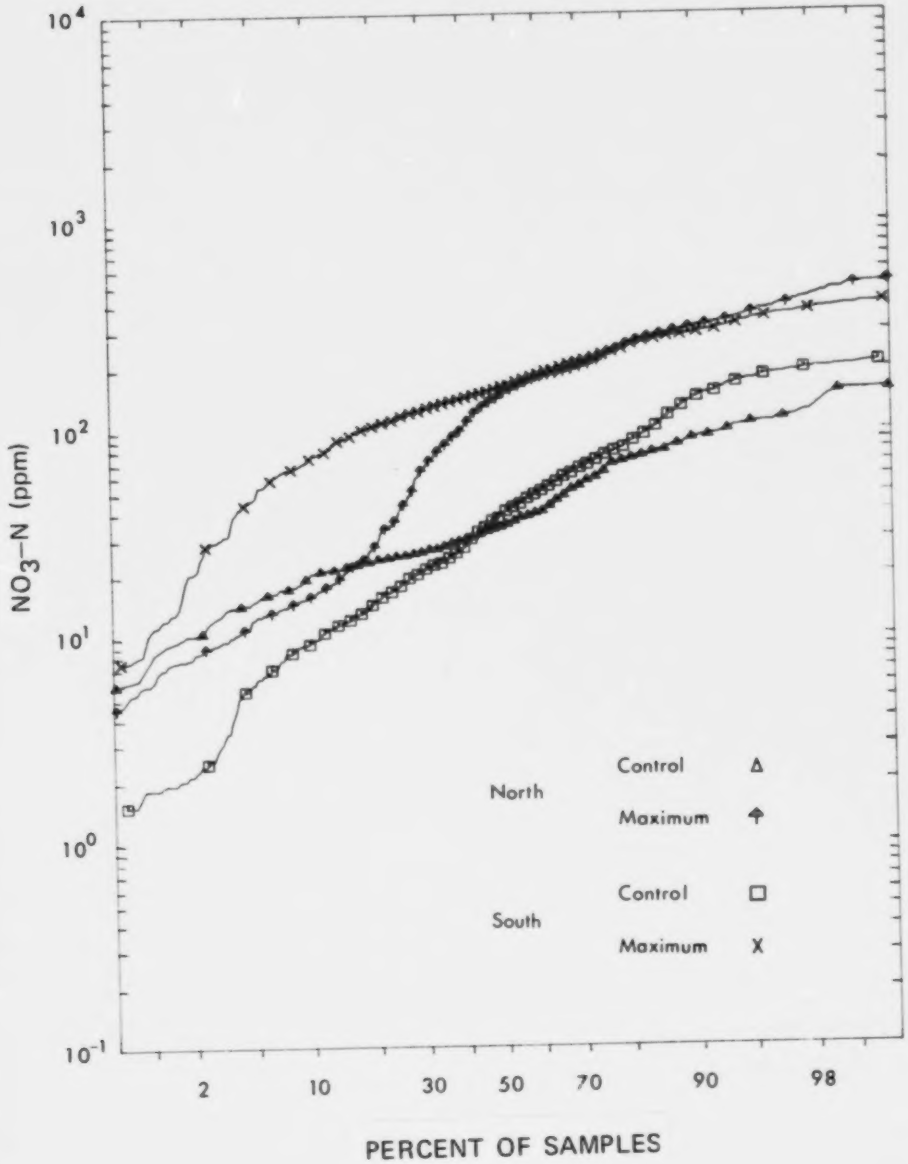

Figure 21. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

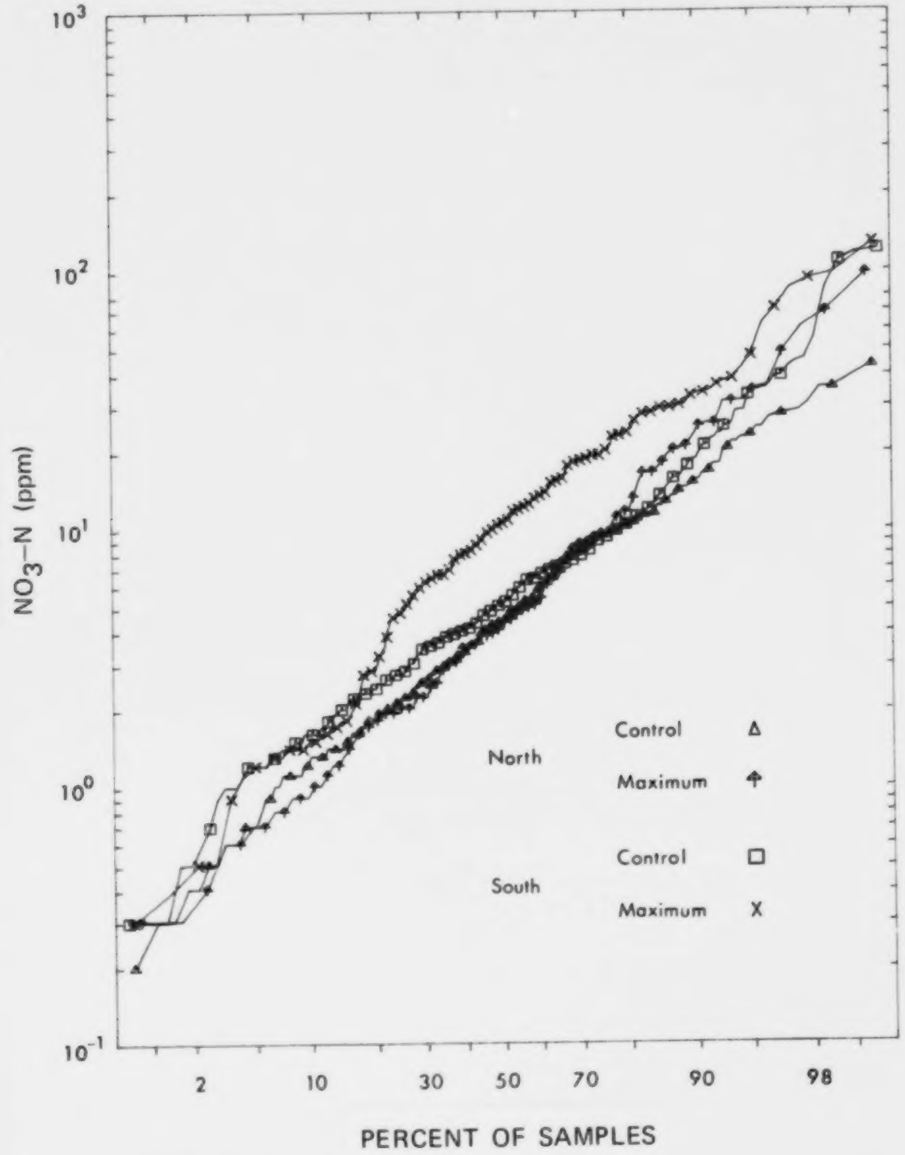

Figure 22. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

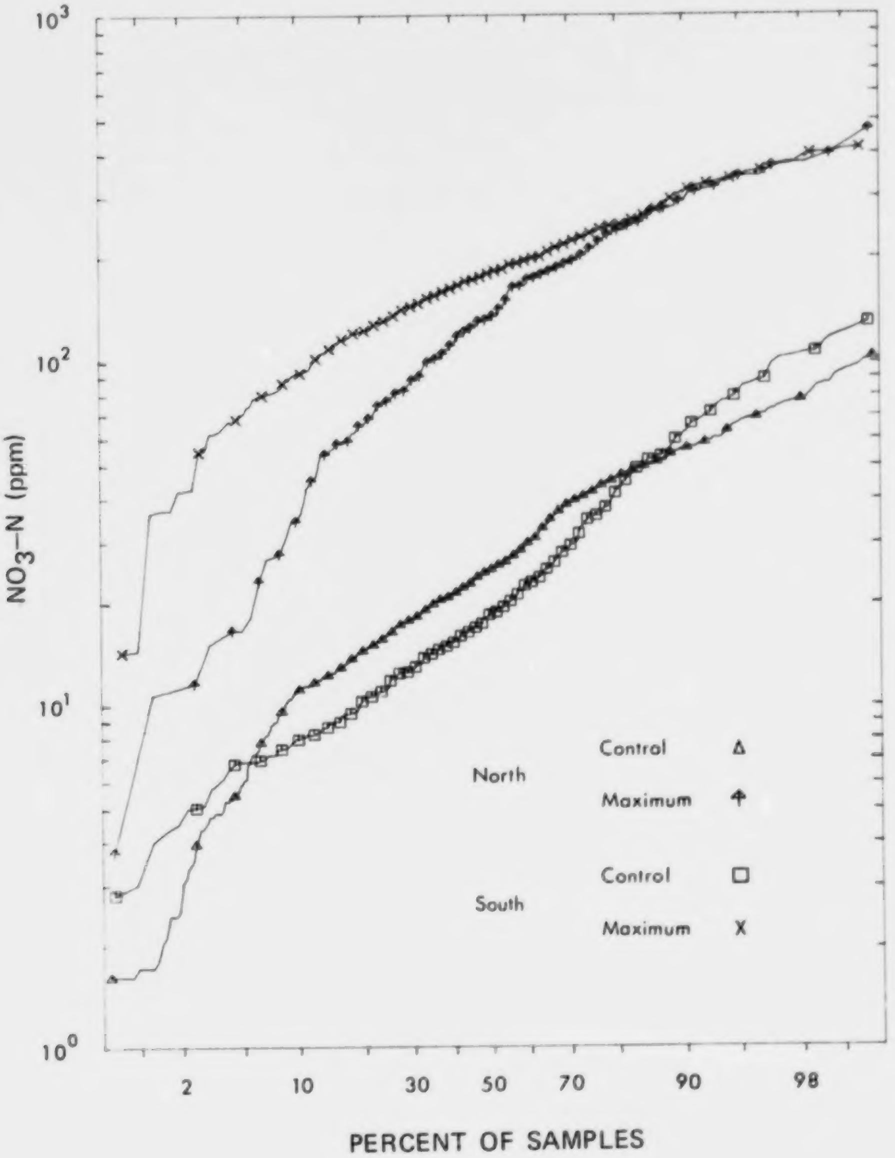

Figure 23. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

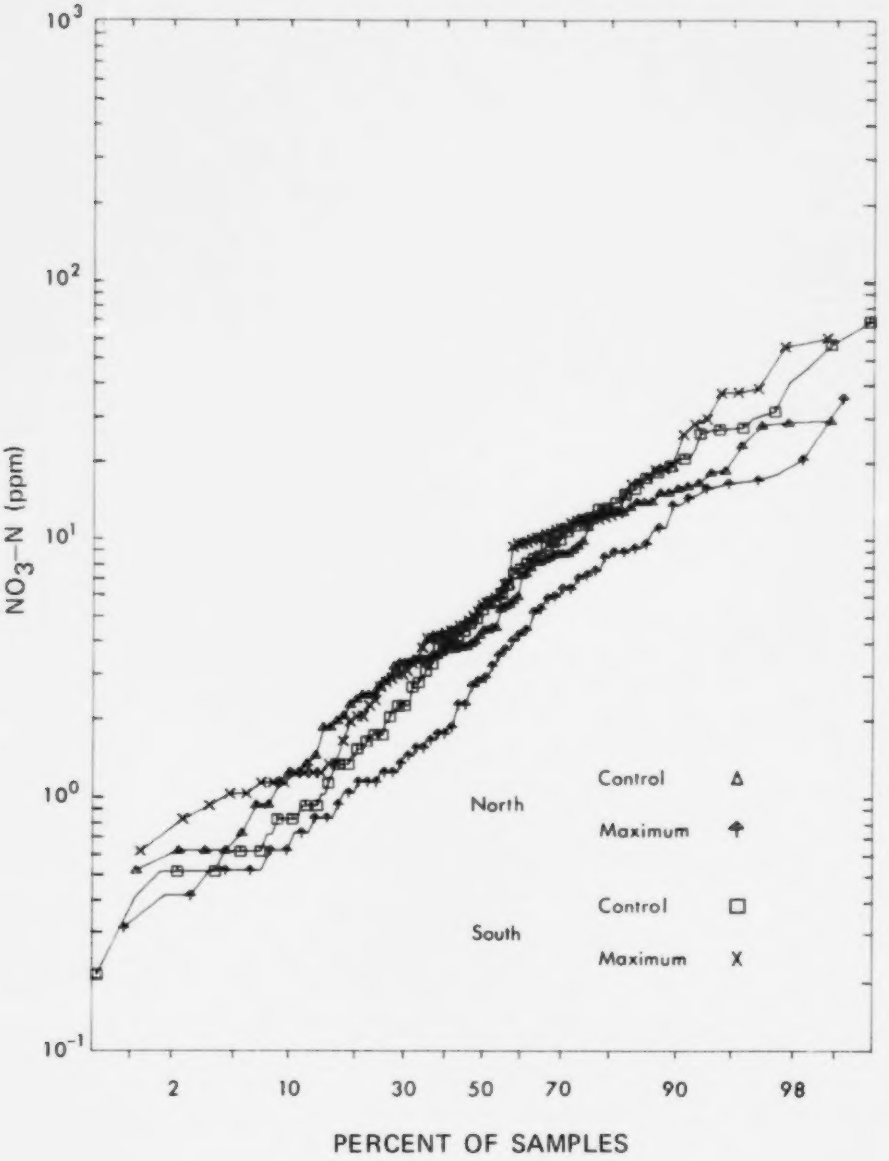

Figure 24. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

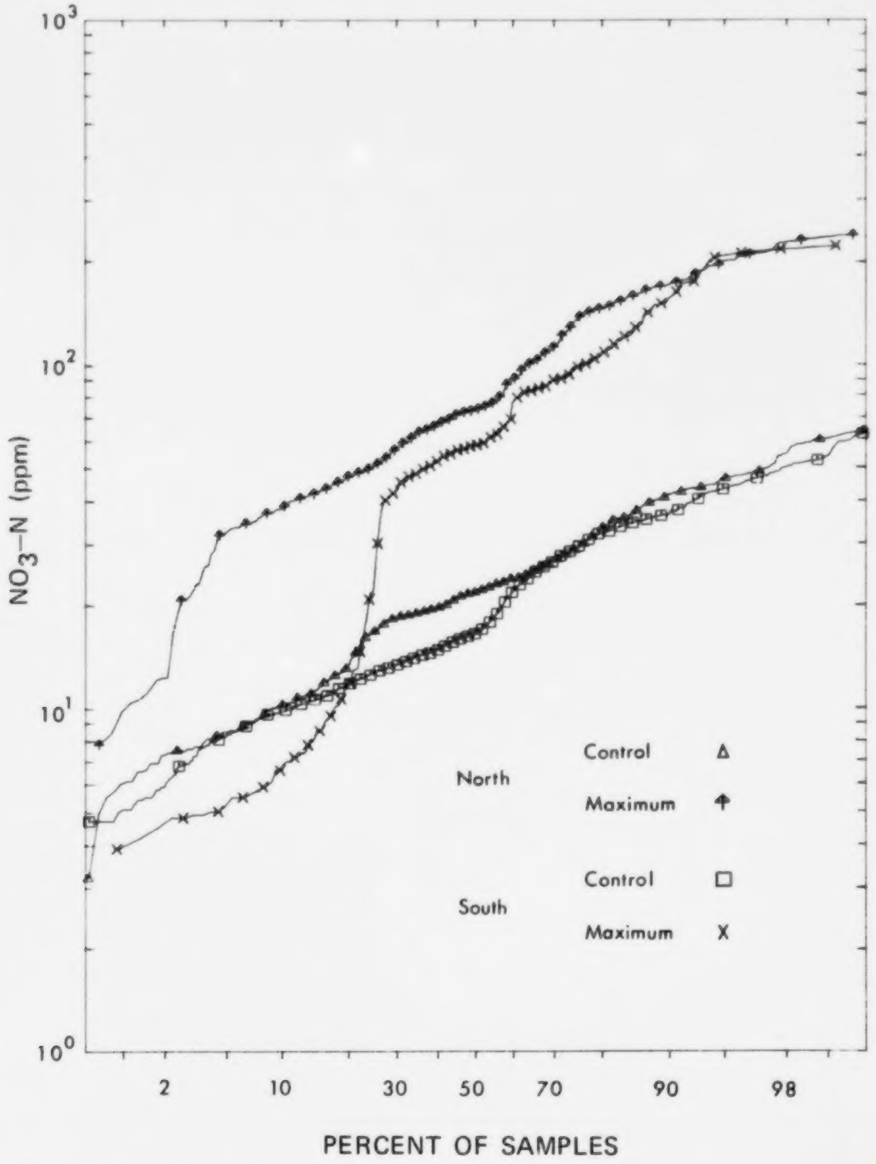

Figure 25. Frequency distribution of NO_3-N concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of NO_3-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

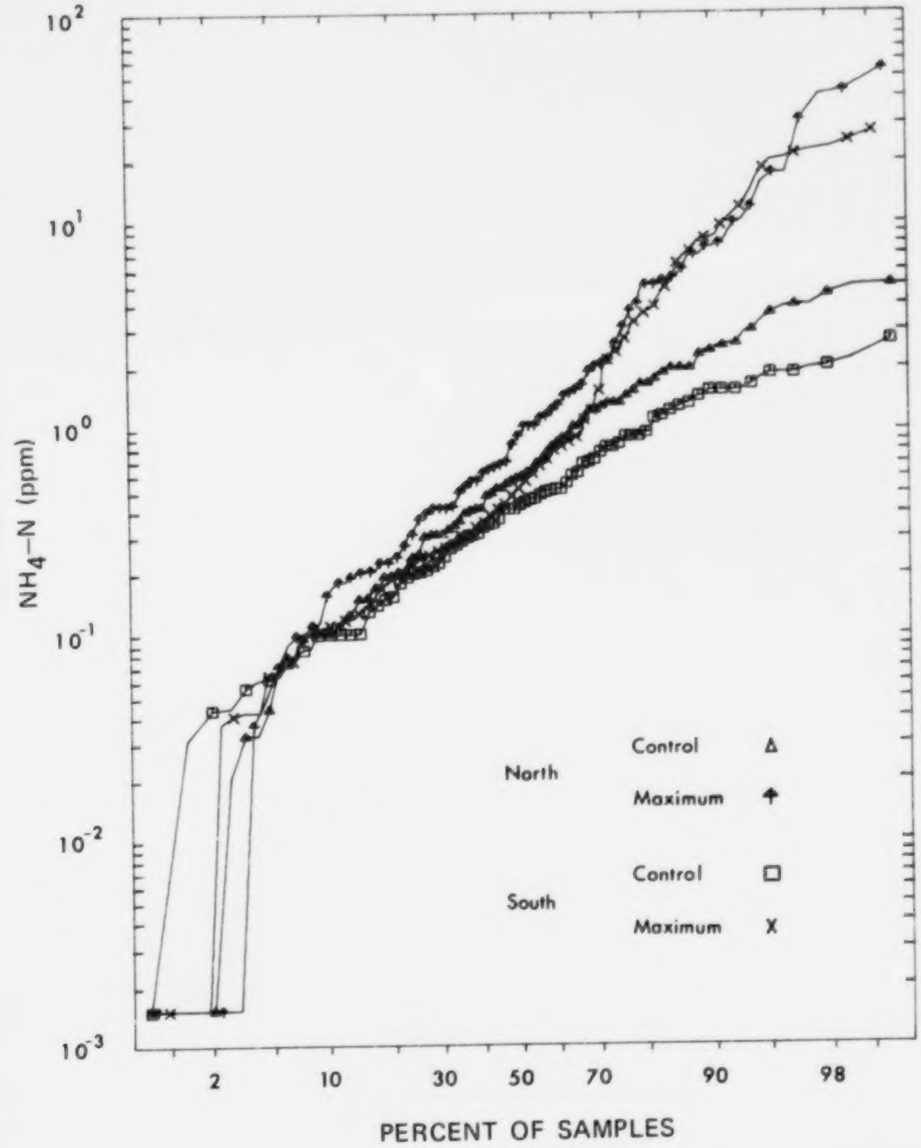

Figure 26. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of NH_4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

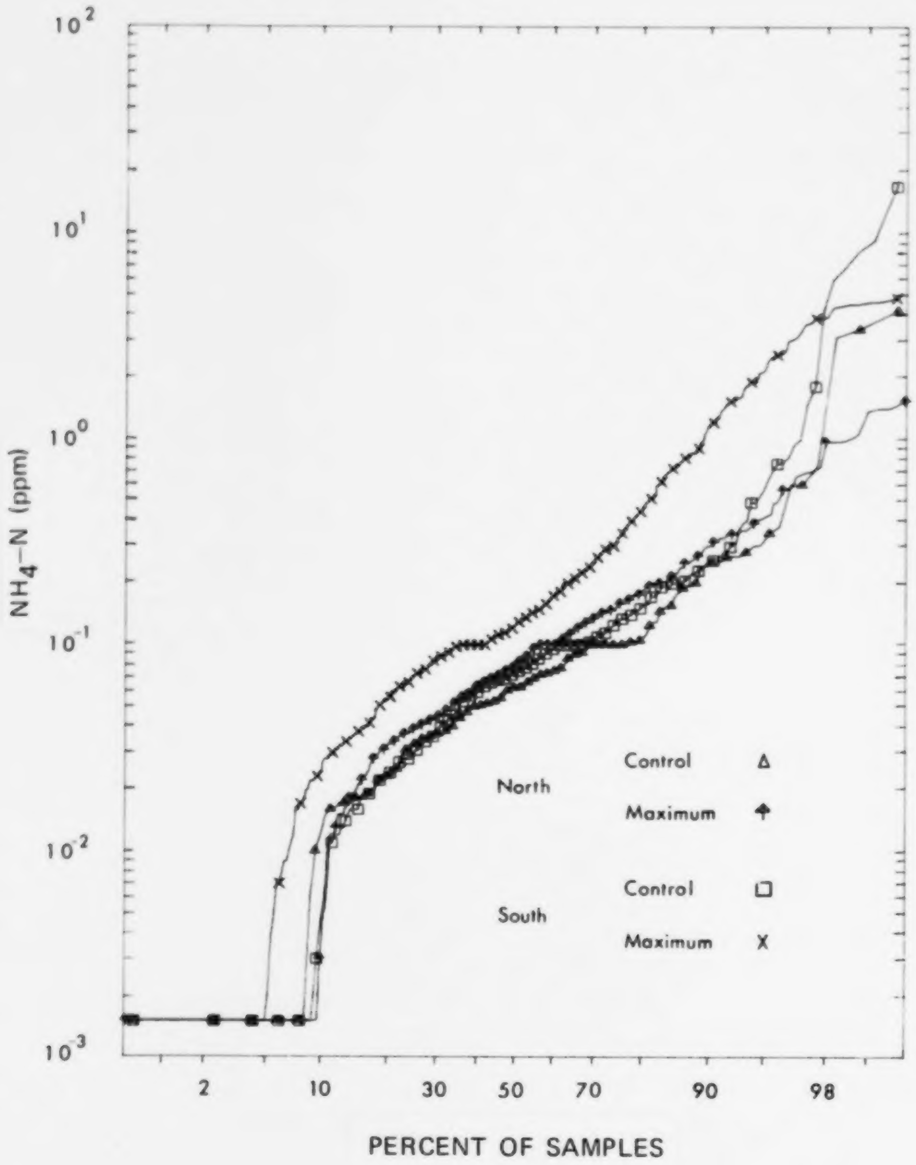

Figure 27. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of NH_4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

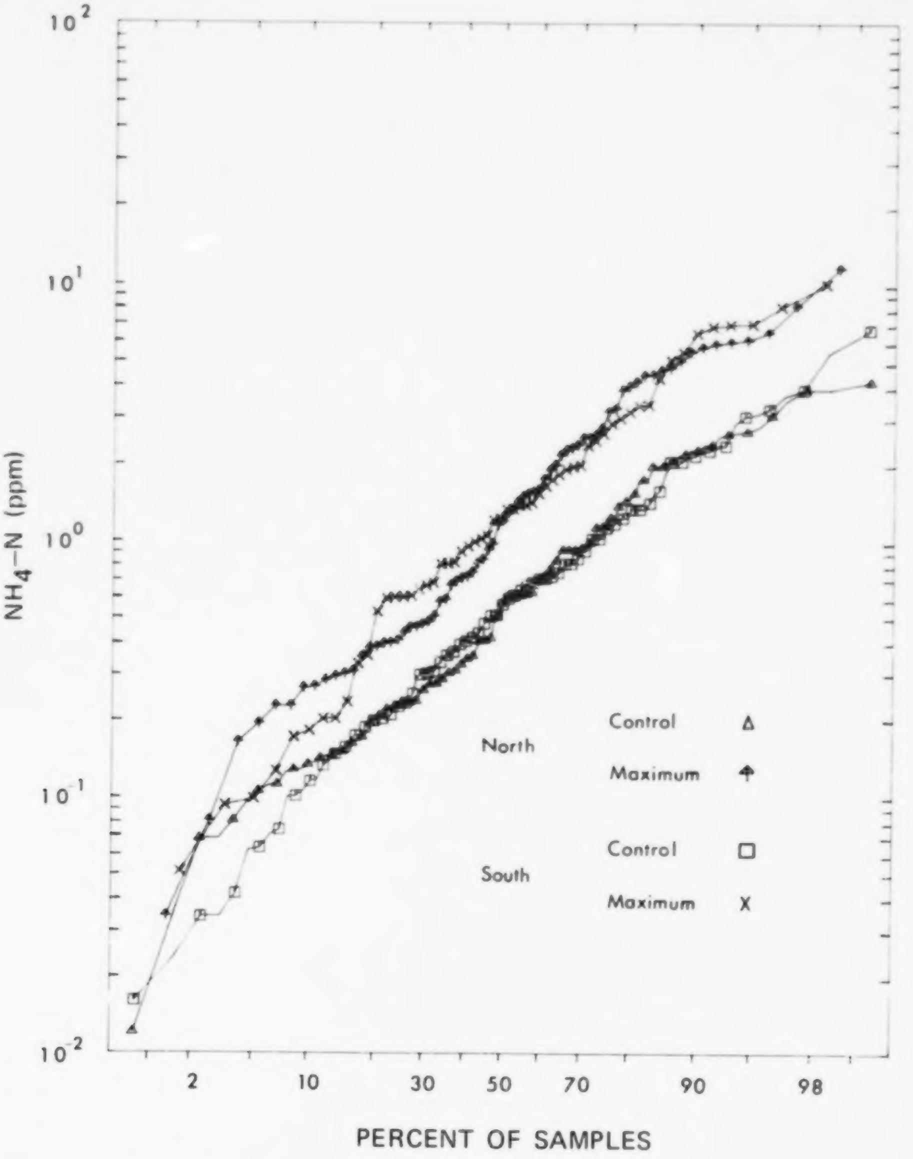

Figure 28. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in runoff water samples collected from field lysimeter plots containing Illiott silt loam soil. Distributions of NH_4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

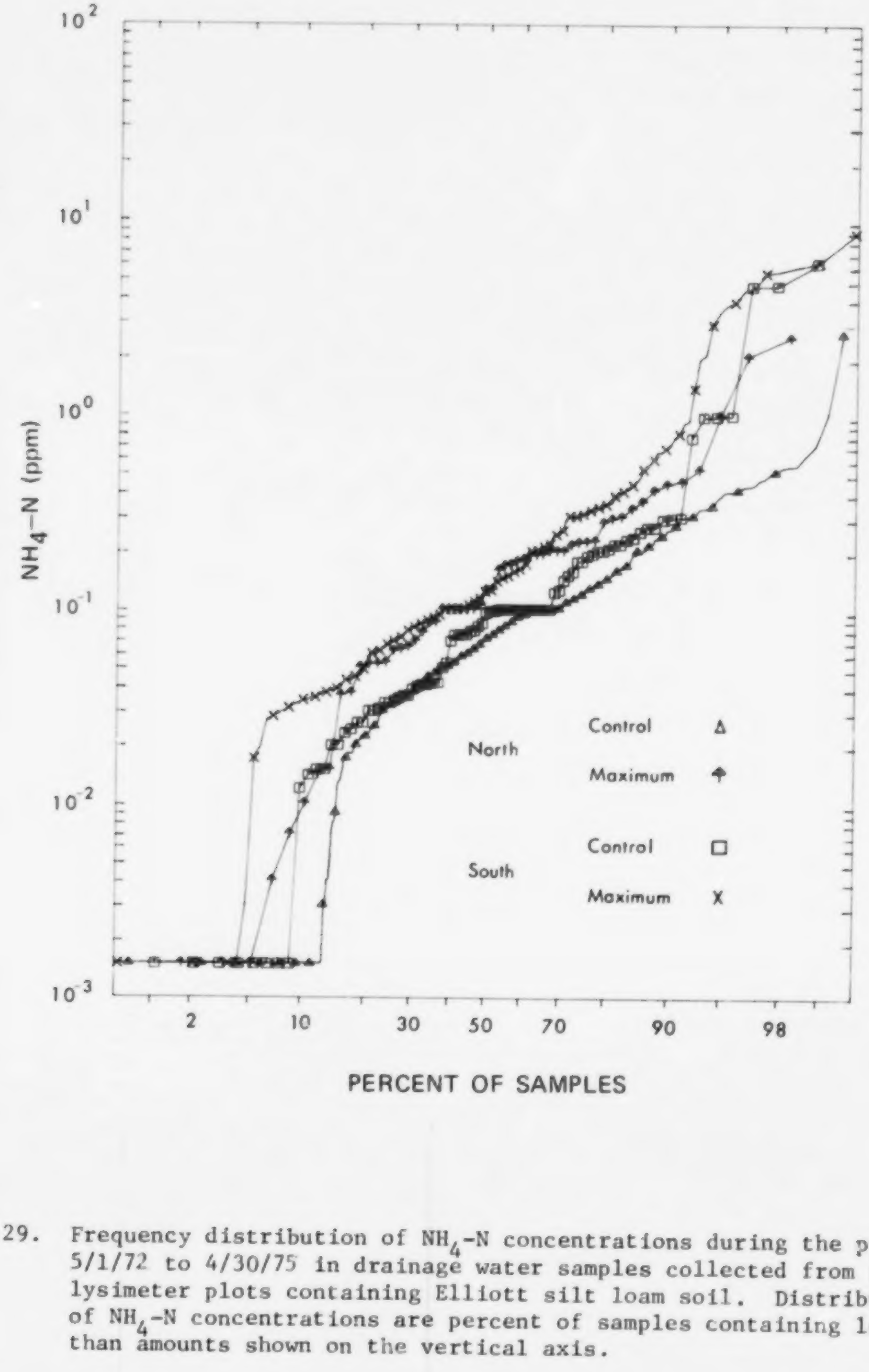

Figure 29. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of NH_4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

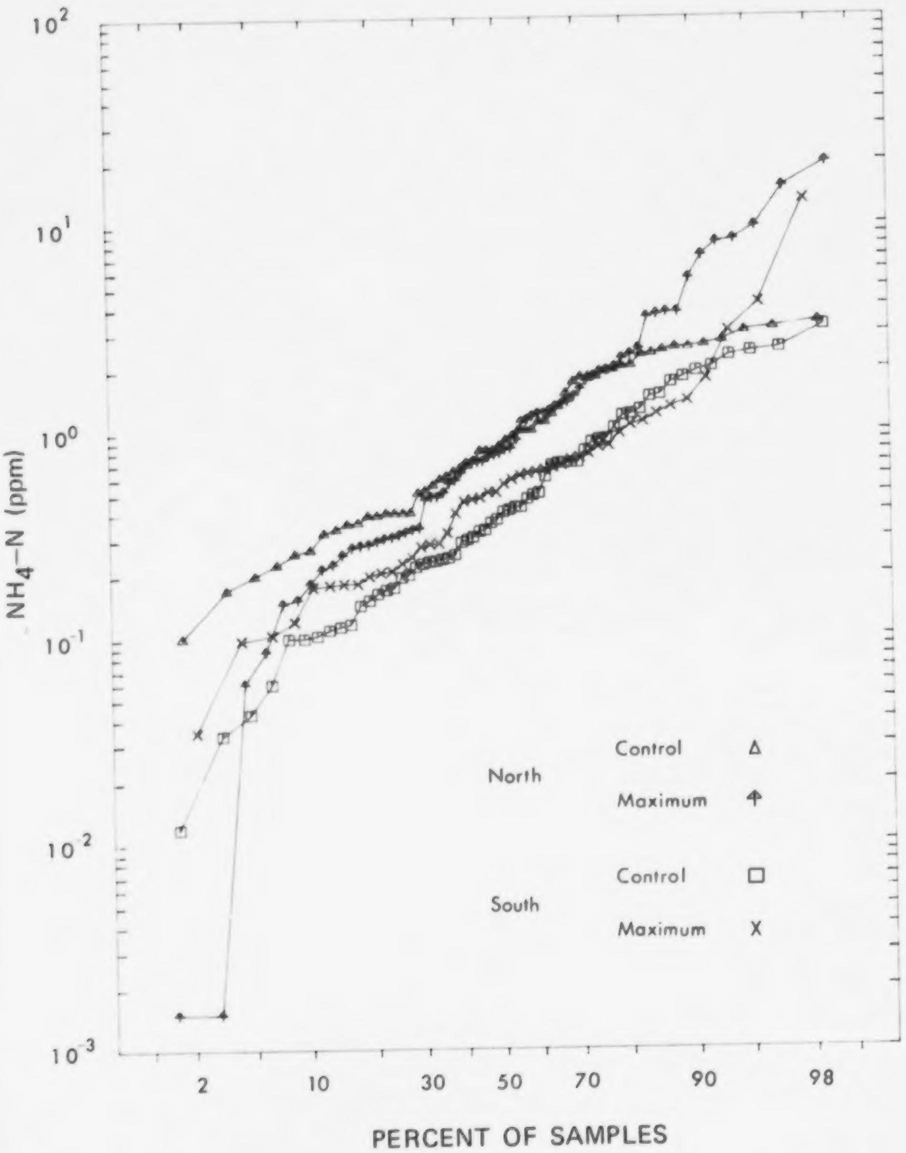

Figure 30. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of NH4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

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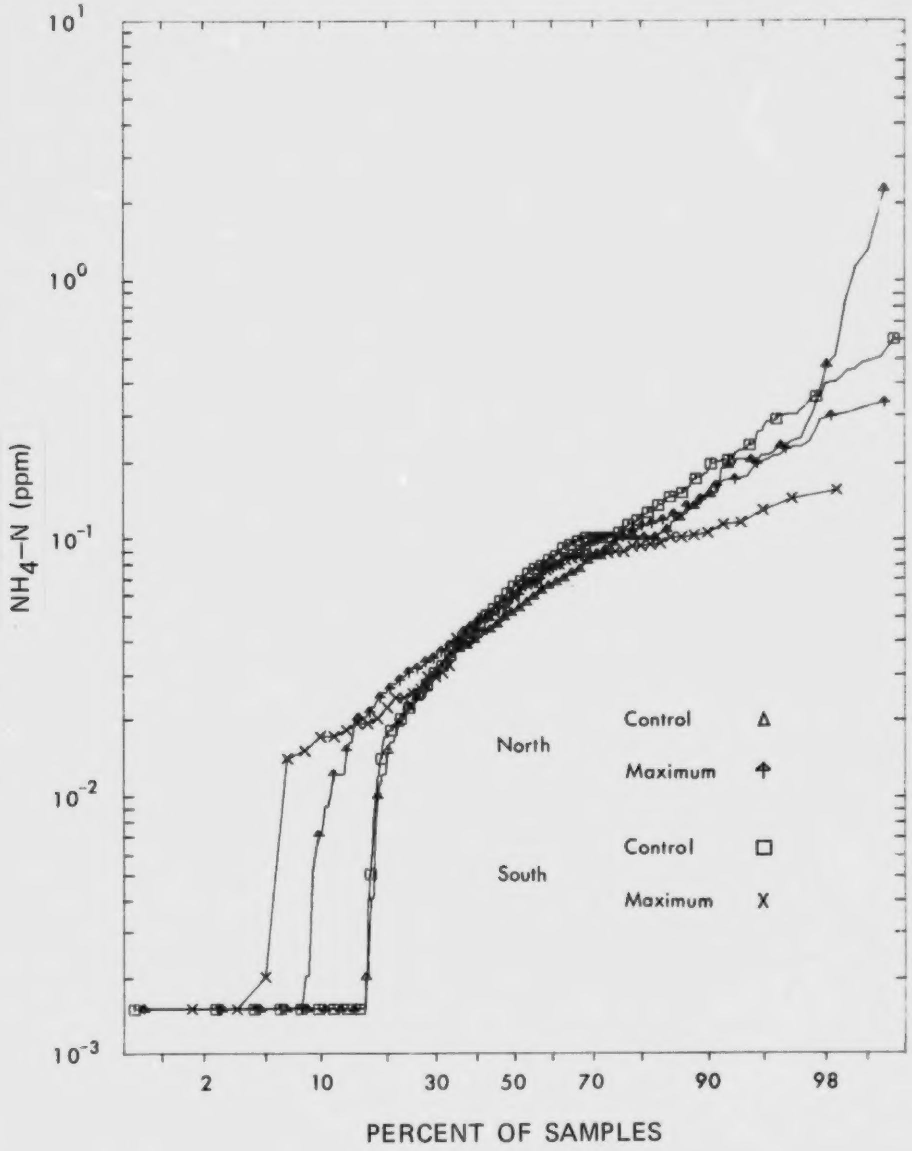

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Figure 31. Frequency distribution of NH_4-N concentrations during the period 5/1/72 to 4/30/75 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of NH_4-N concentrations are percent of samples containing less than amounts shown on the vertical axis.

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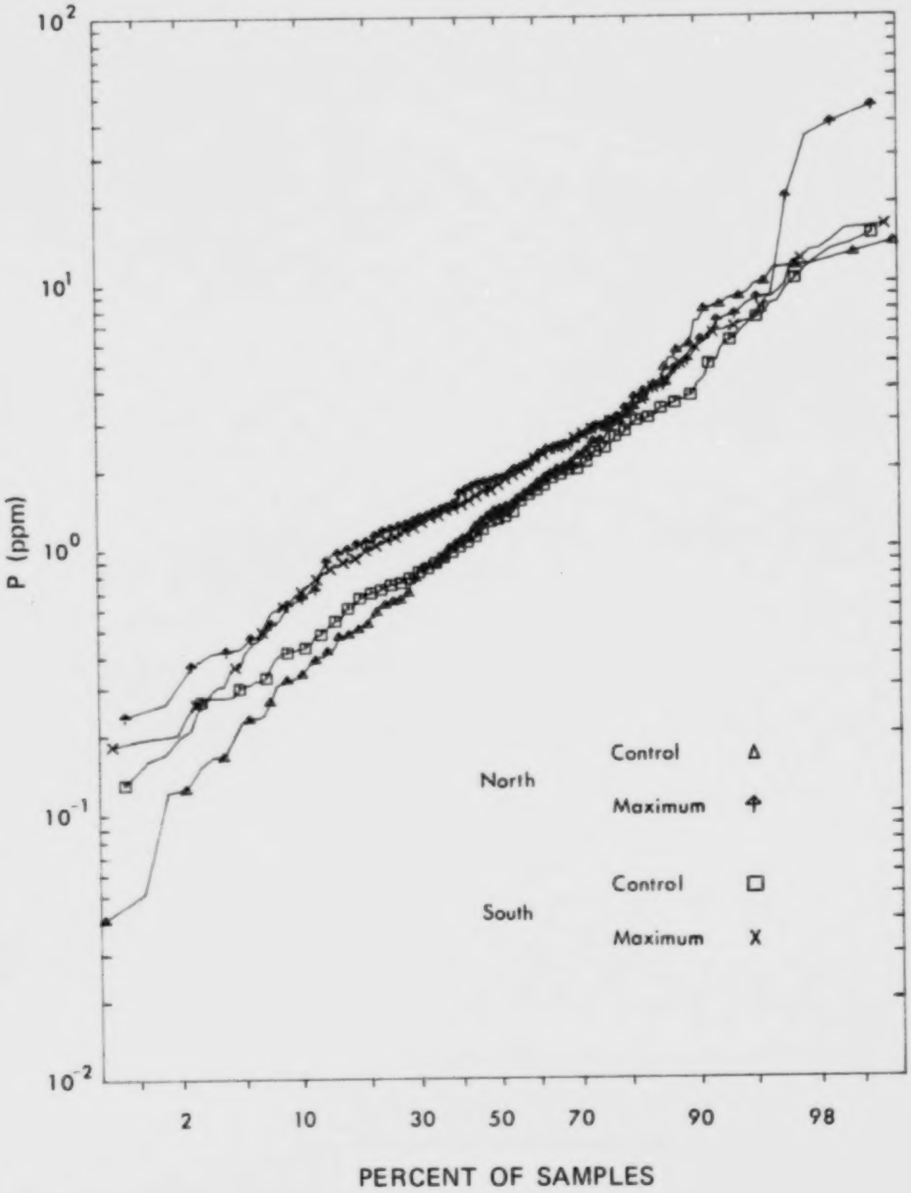

Figure 32. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

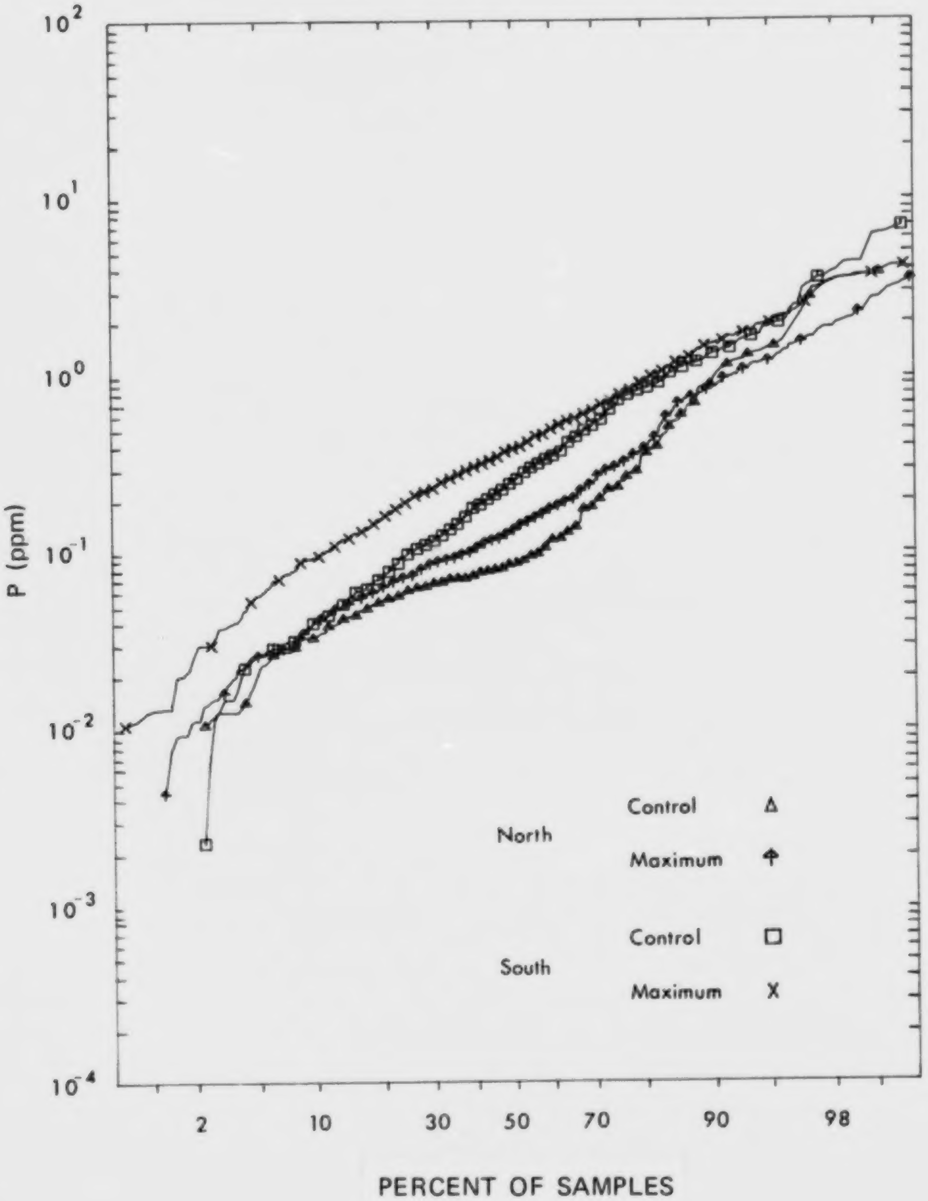

Figure 33. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/76 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

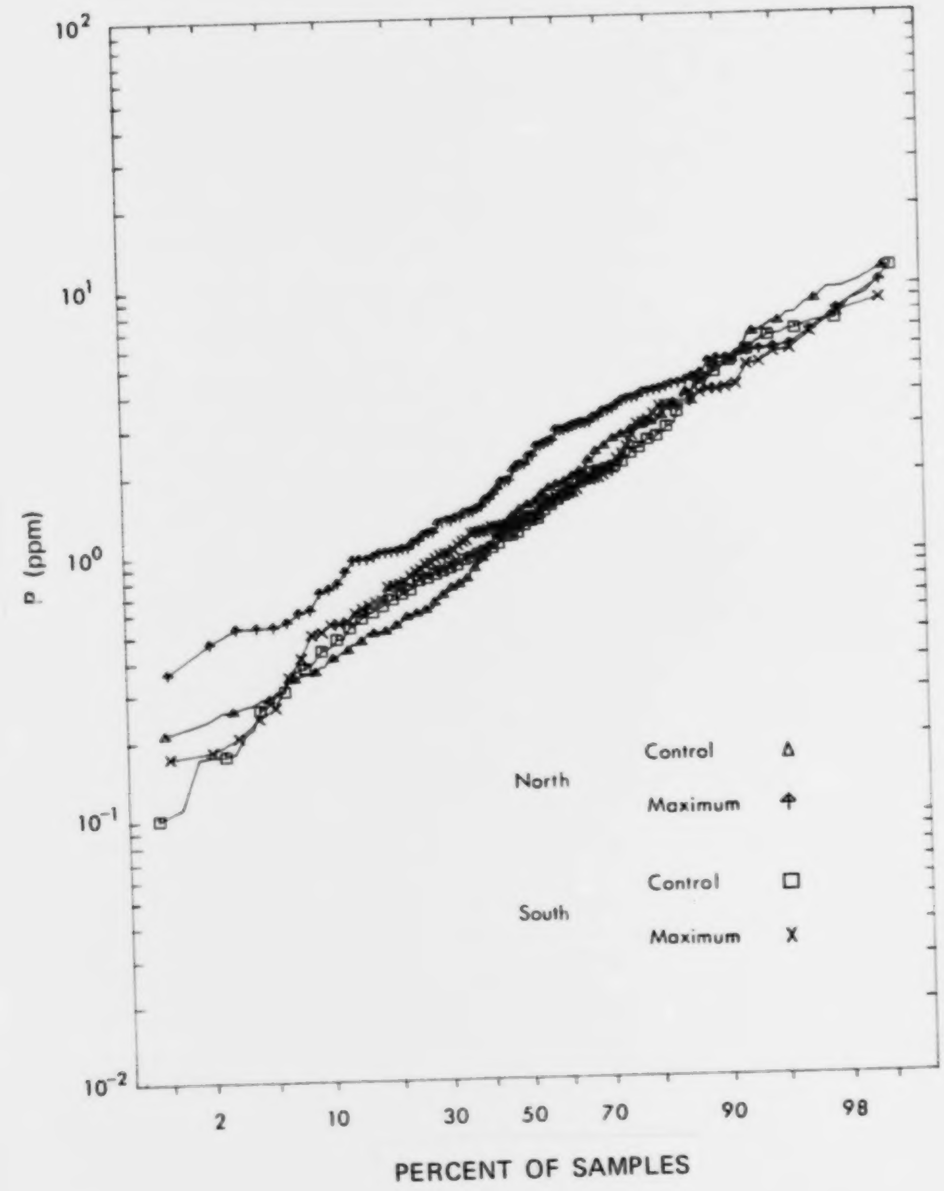

Figure 34. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

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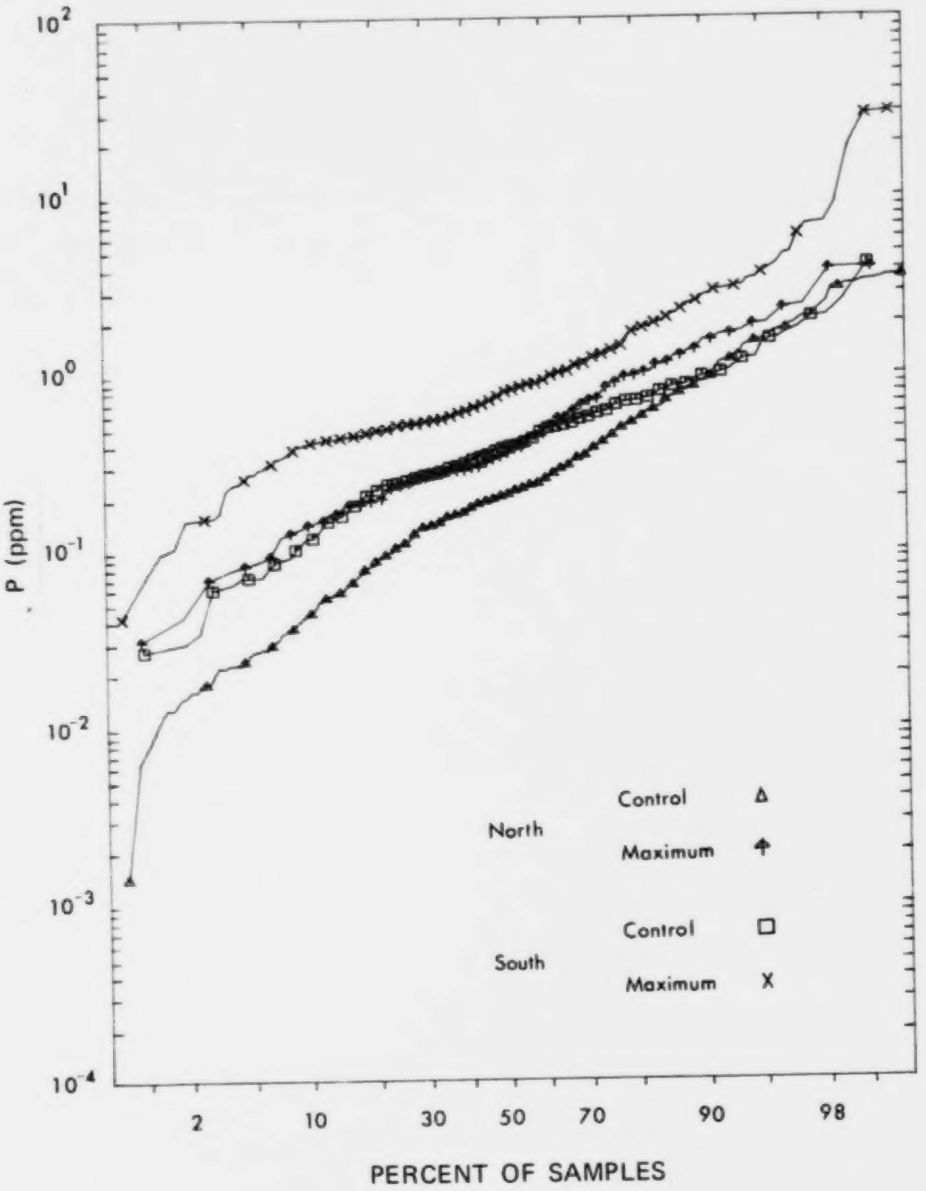

Figure 35. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/76 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

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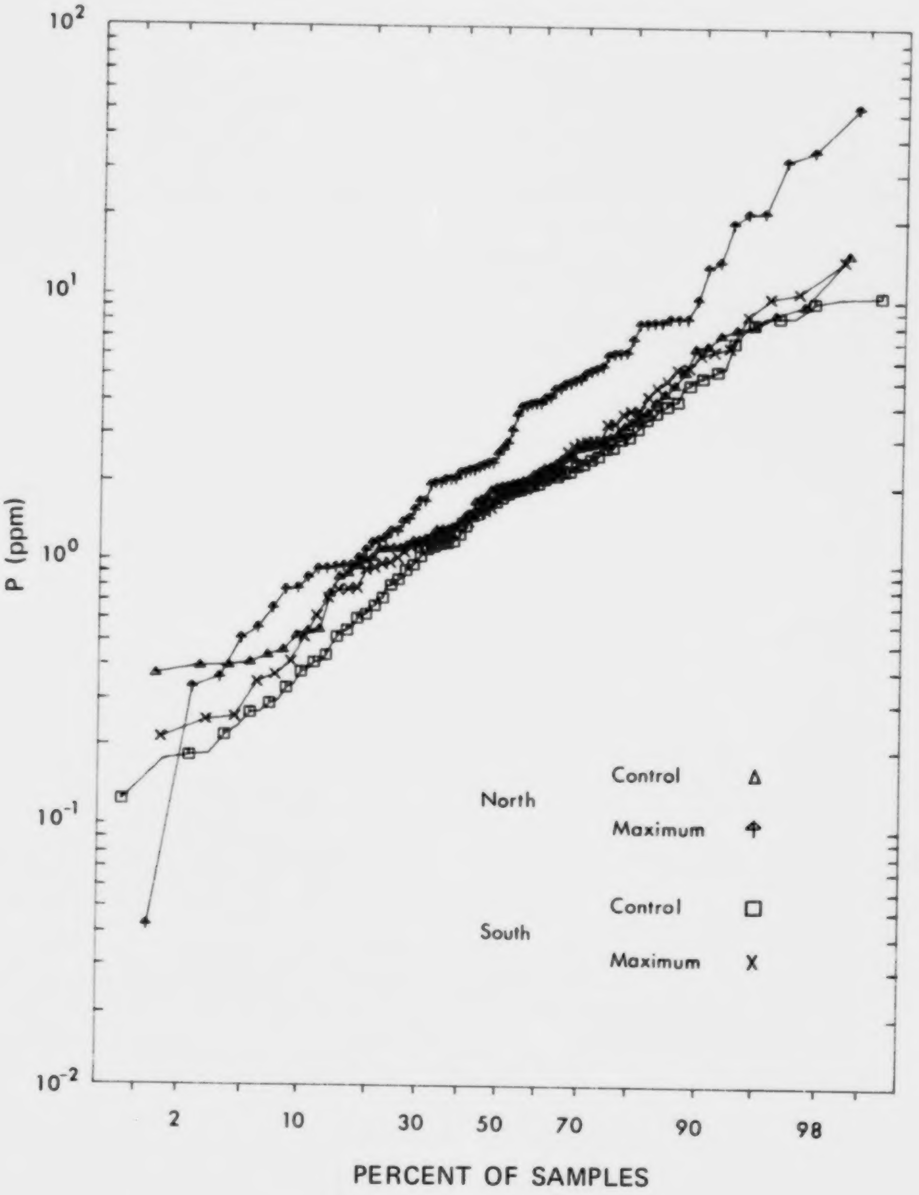

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Figure 36. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

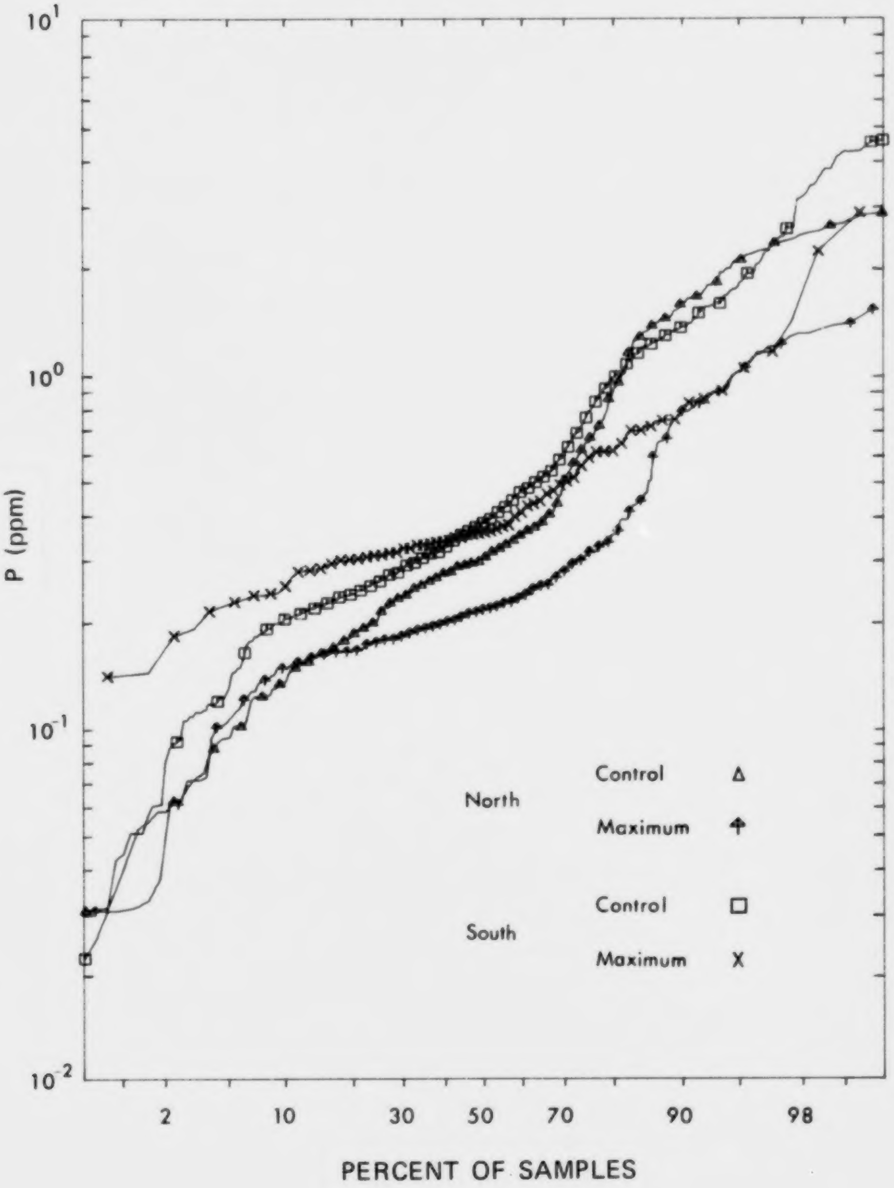

Figure 37. Frequency distribution of P concentrations during the period 5/1/71 to 4/30/76 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of P concentrations are percent of samples containing less than amounts shown on the vertical axis.

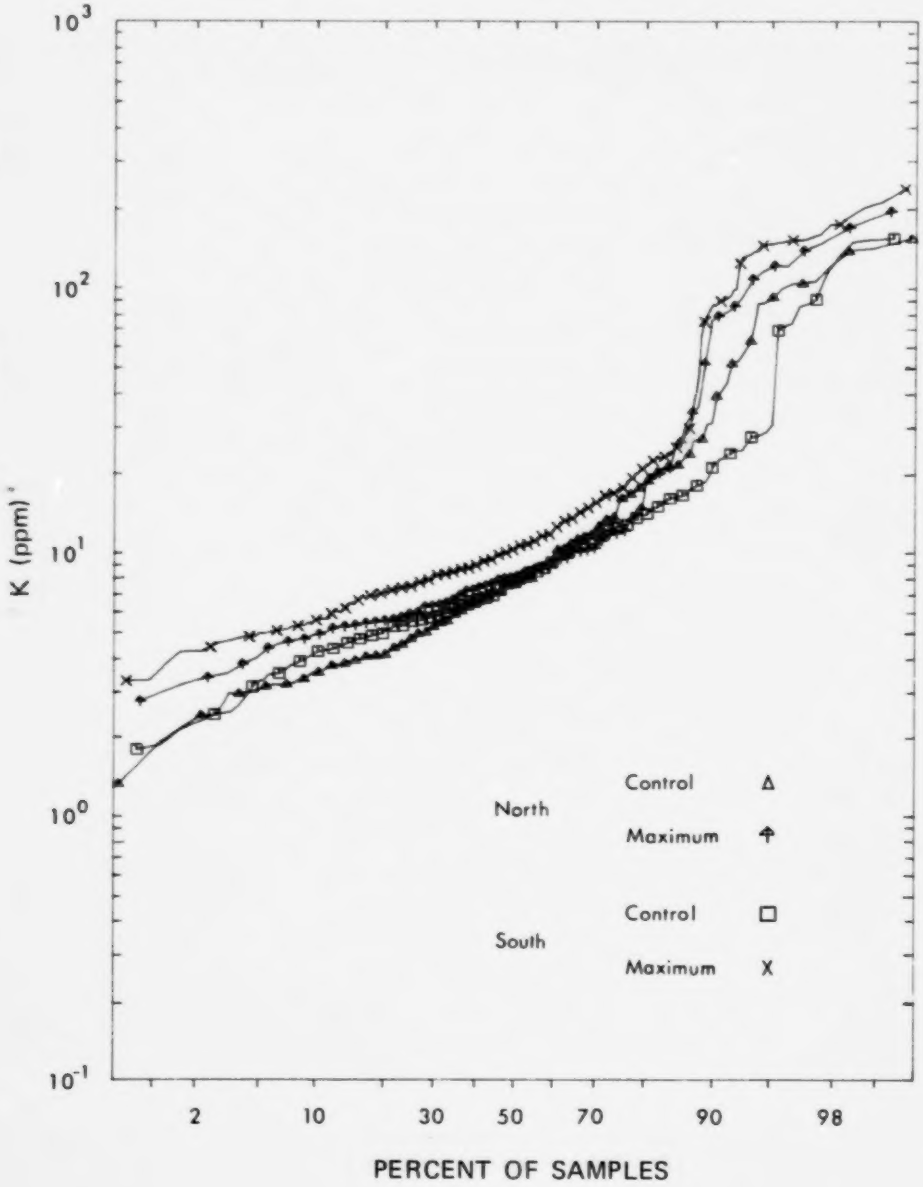

Figure 38. Frequency distribution of K concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

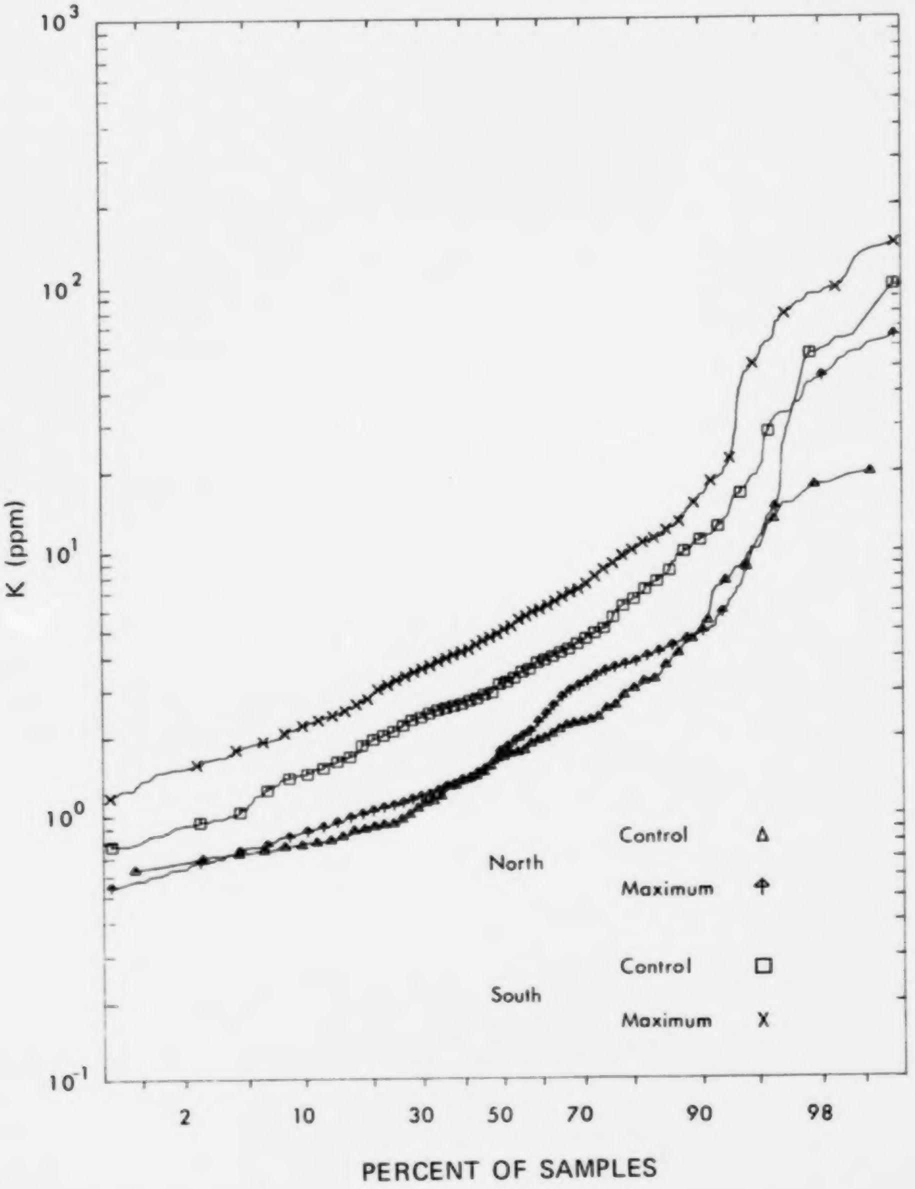

Figure 39. Frequency distribution of K concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

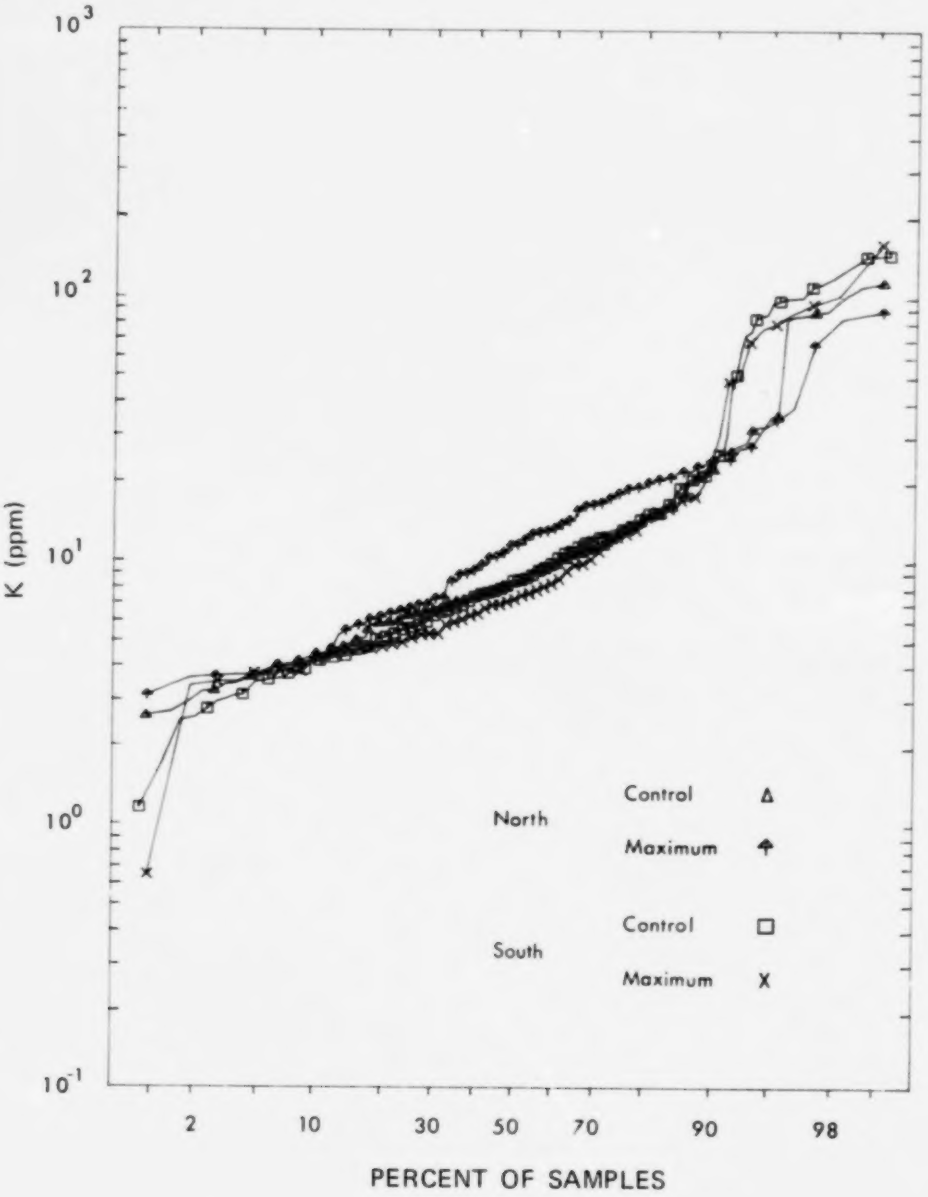

Figure 40. Frequency distribution of K concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

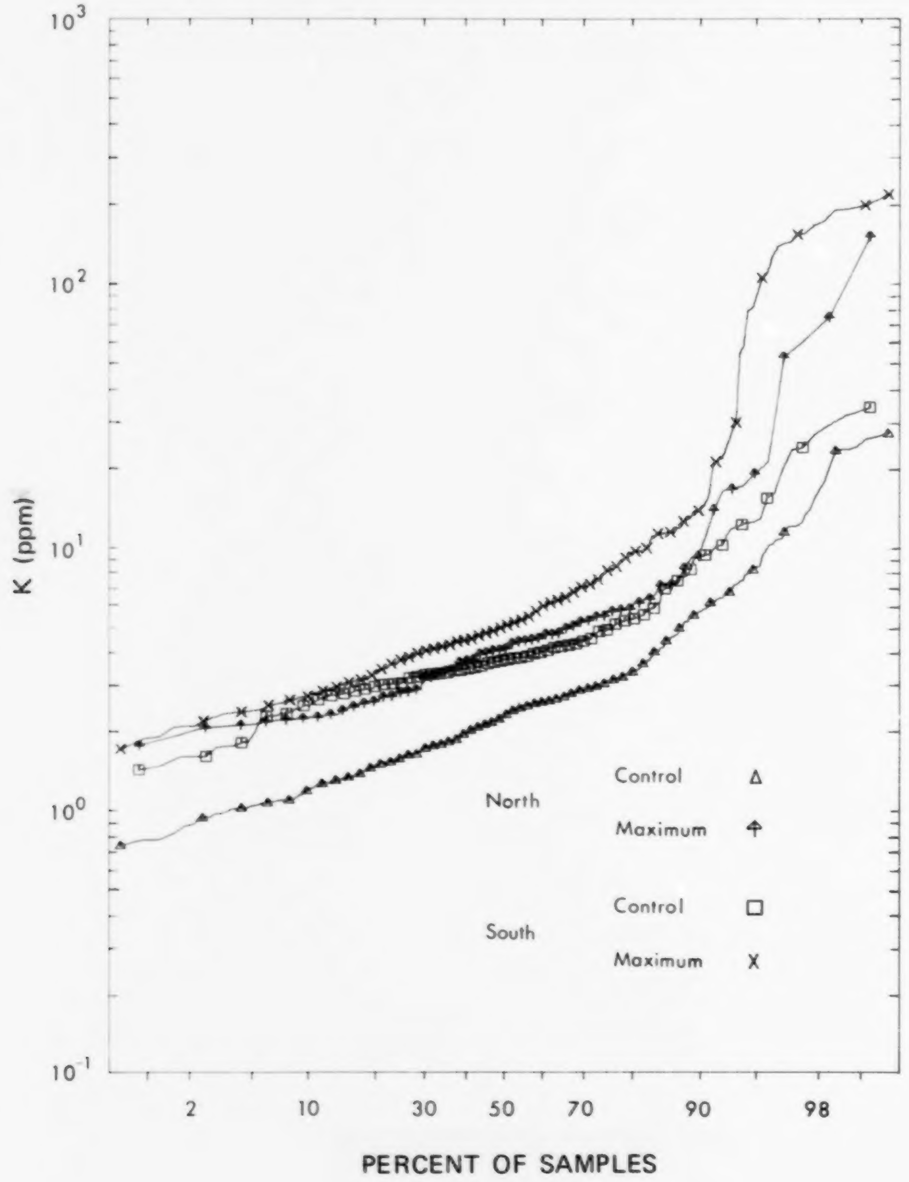

Figure 41. Frequency distribution of K concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

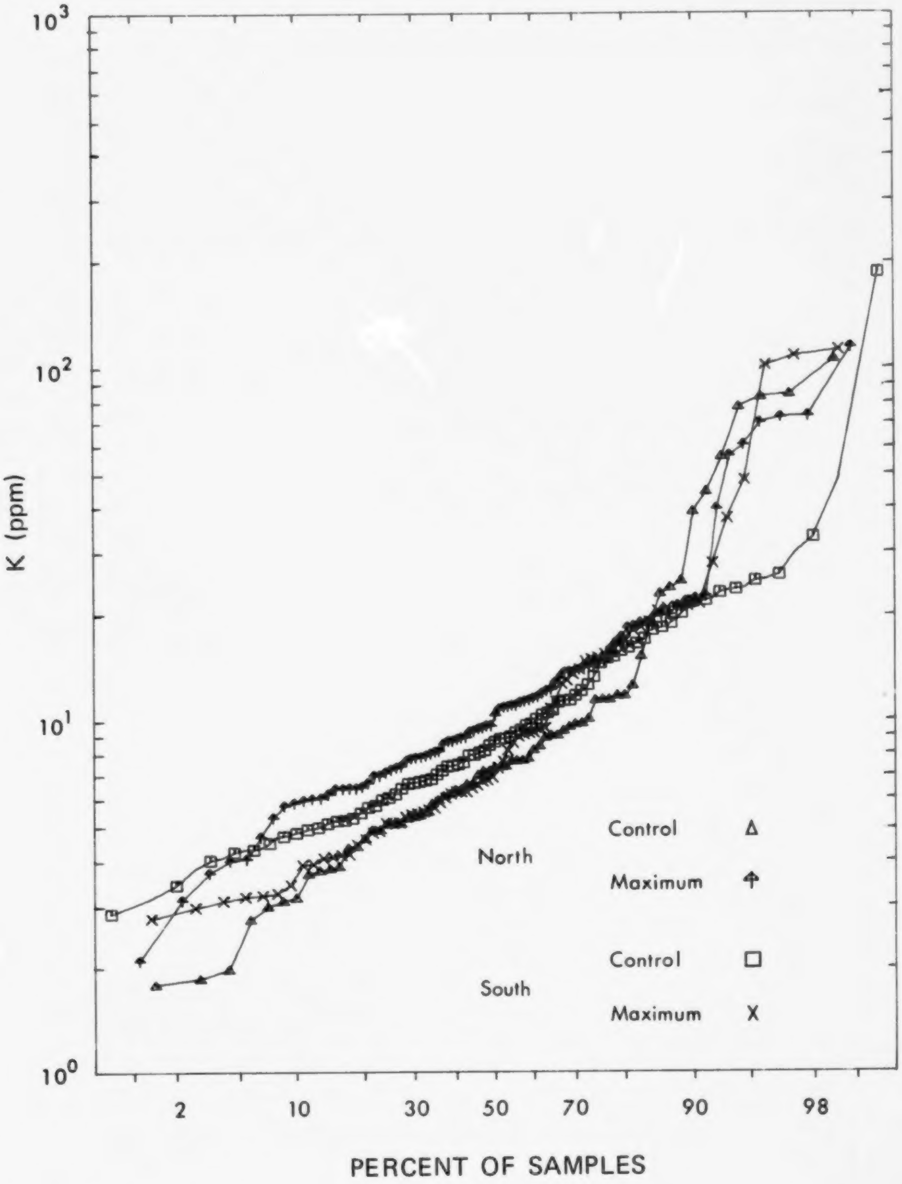

Figure 42. Frequency distribution of K concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

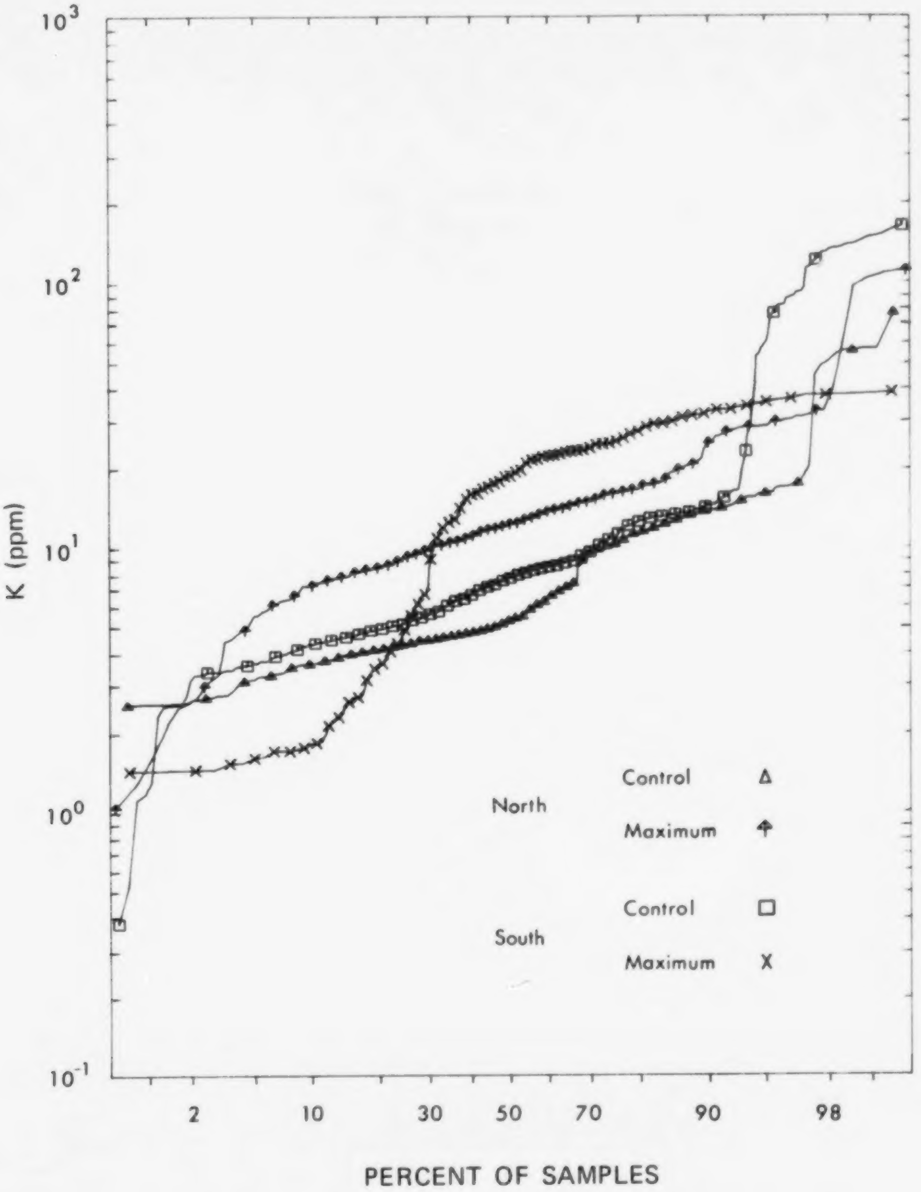

Figure 43. Frequency distributions of K concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of K concentrations are percent of samples containing less than amounts shown on the vertical axis.

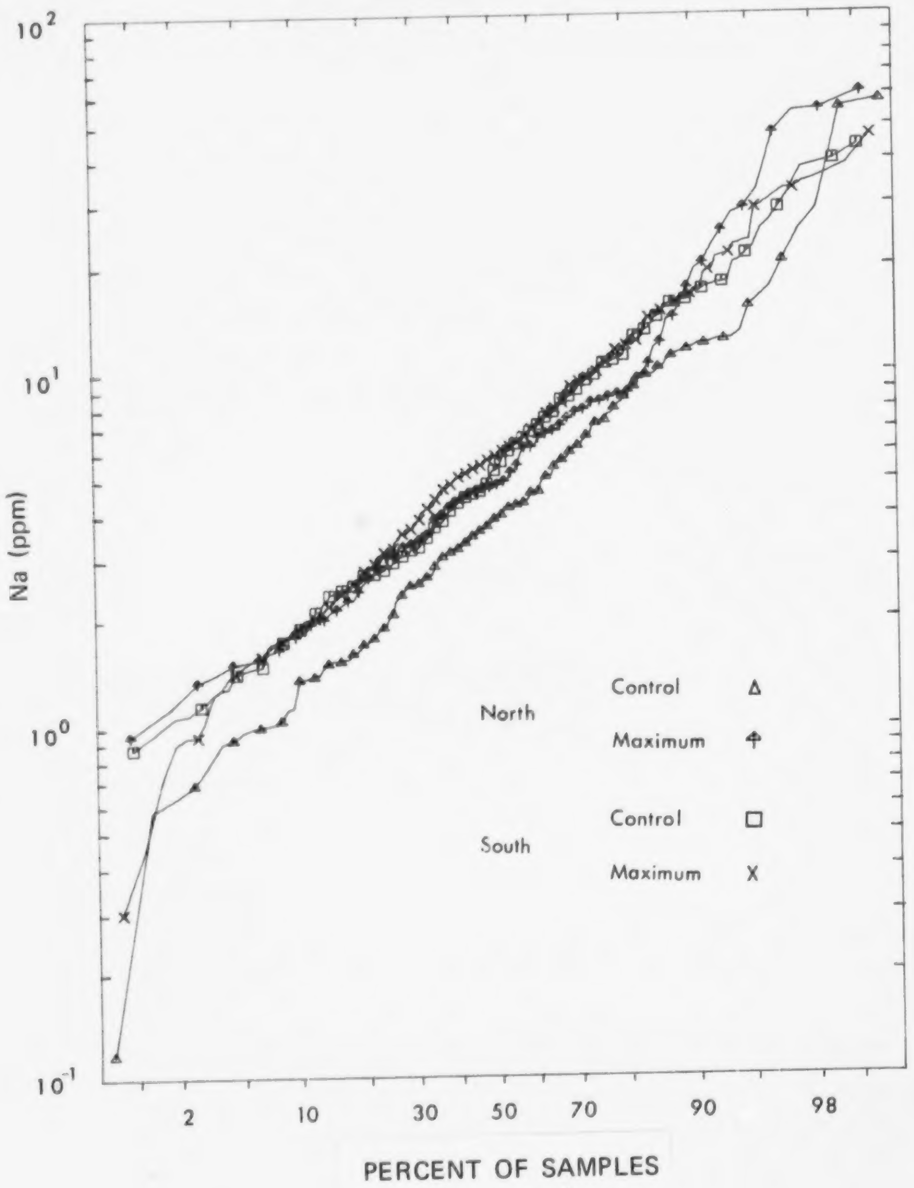

Figure 44. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

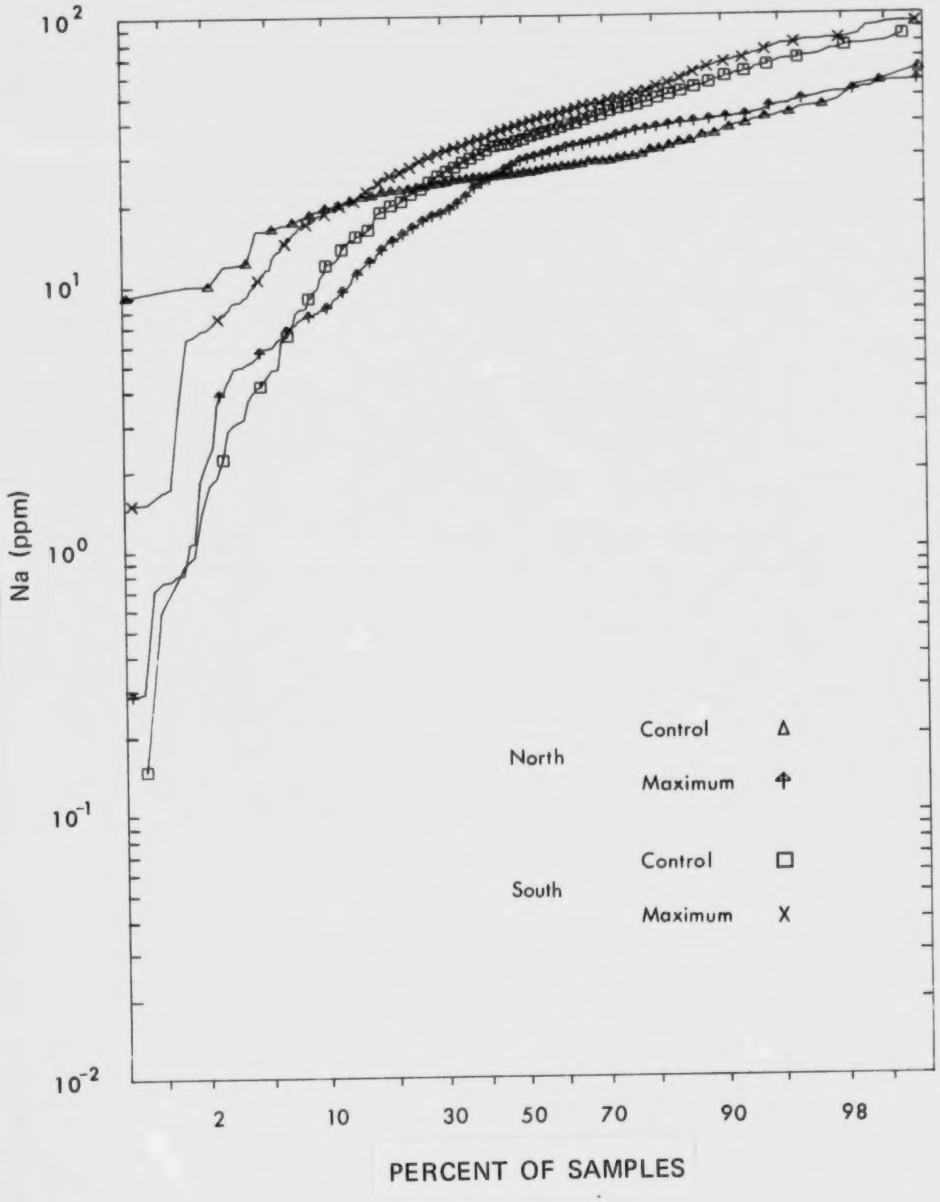

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Figure 45. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

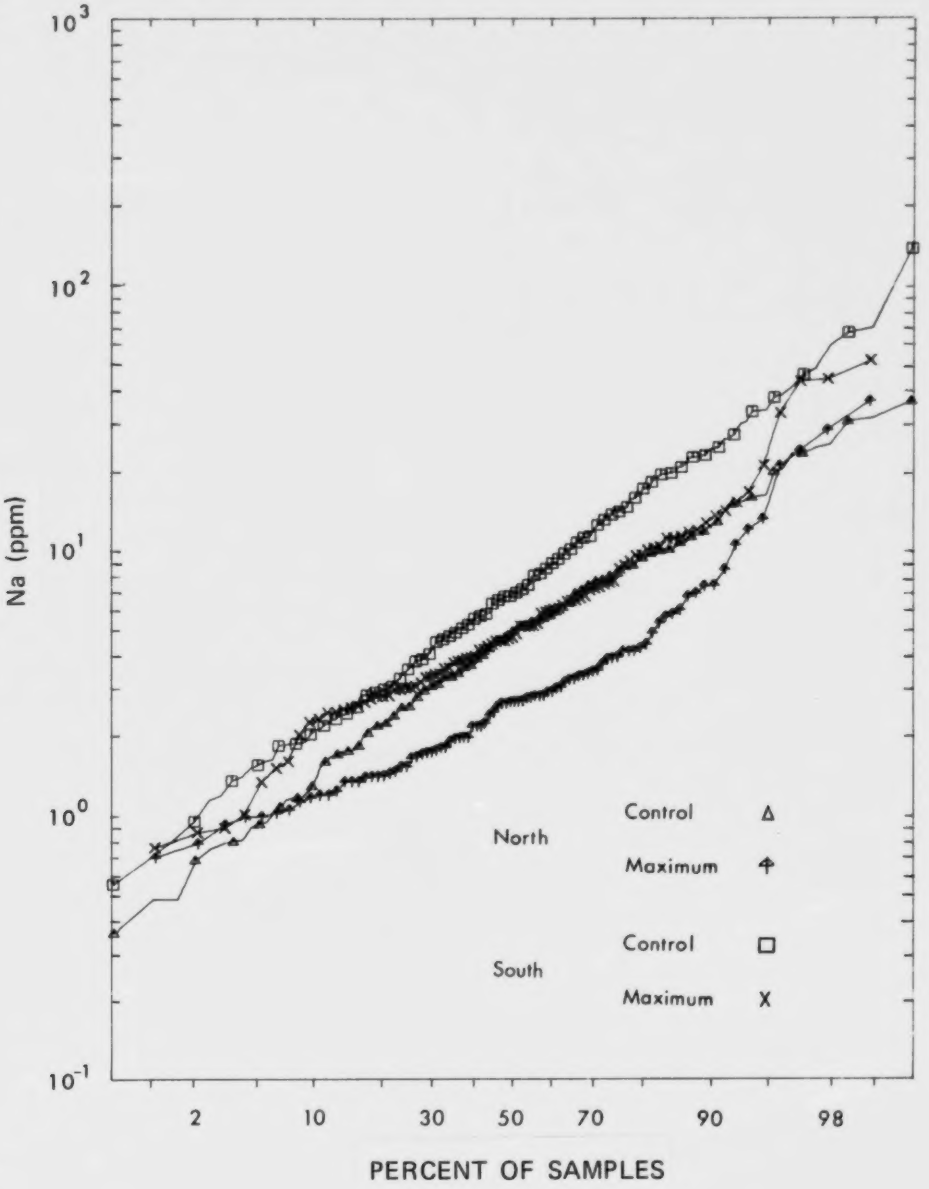

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Figure 46. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

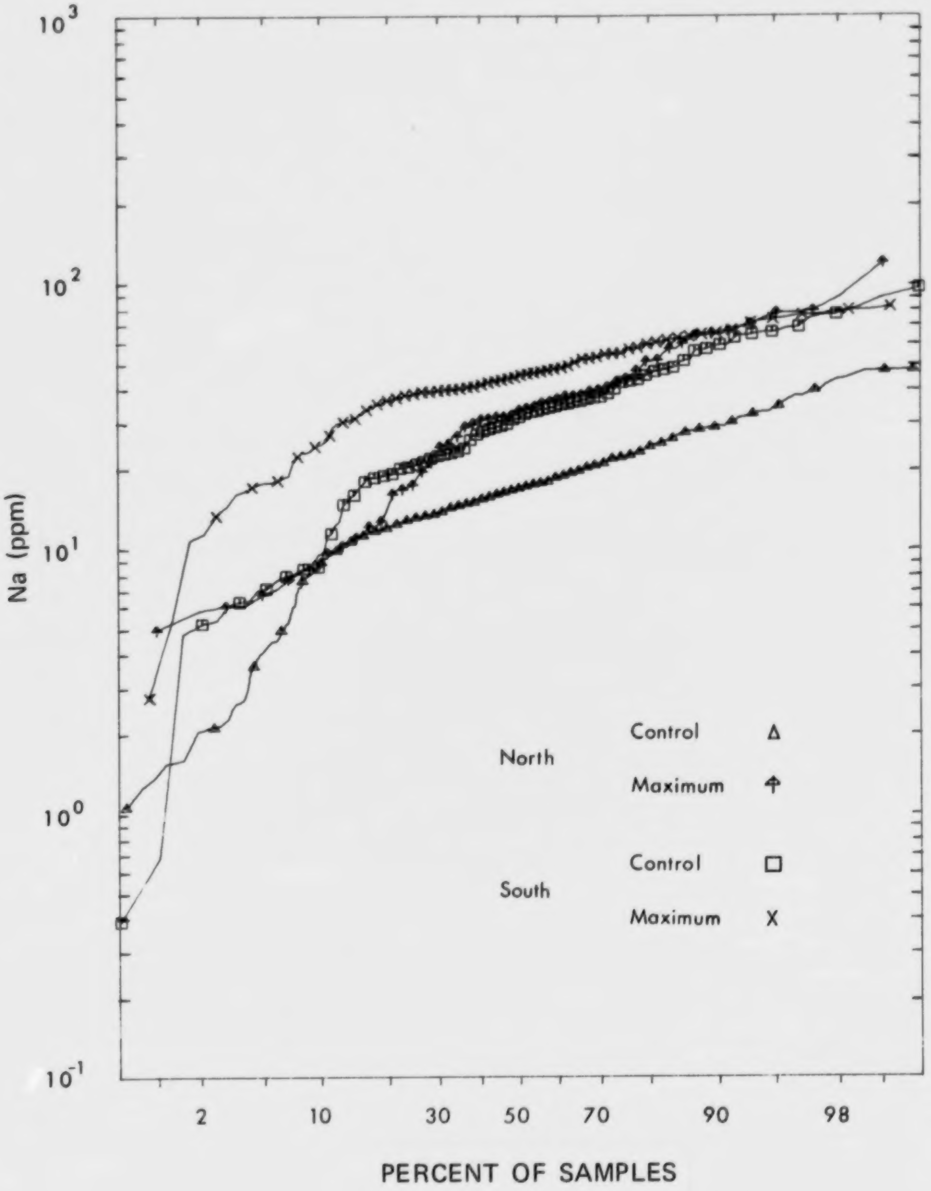

Figure 47. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

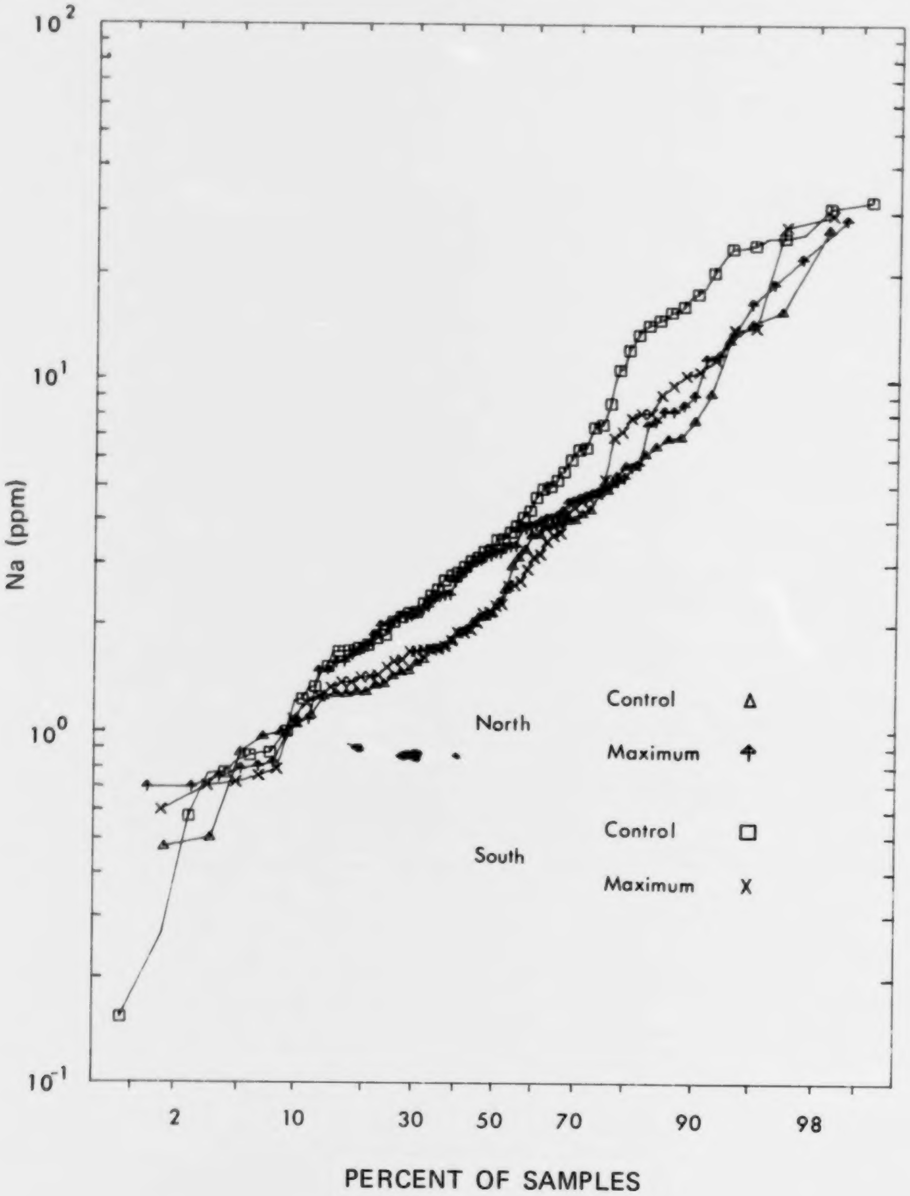

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Figure 48. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

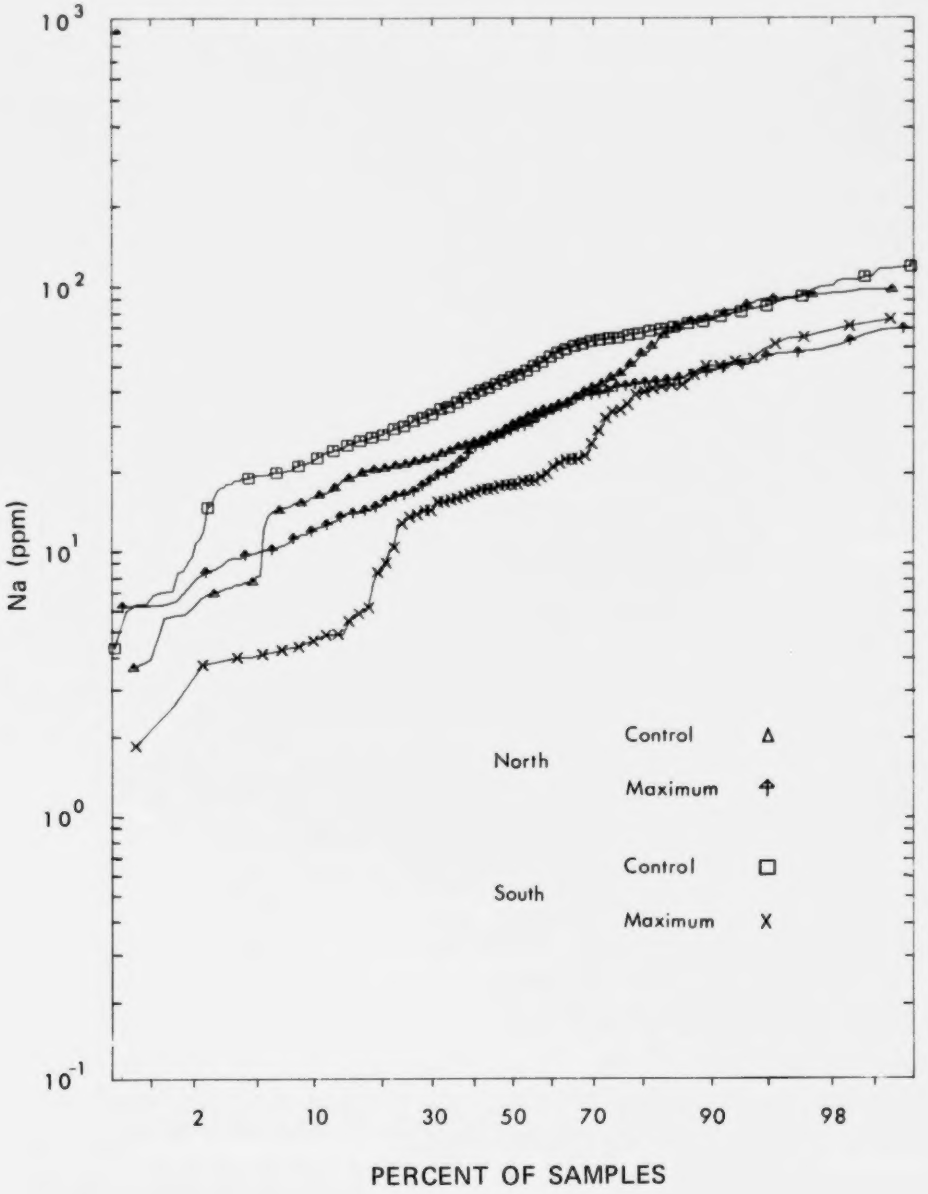

Figure 49. Frequency distribution of Na concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Na concentrations are percent of samples containing less than amounts shown on the vertical axis.

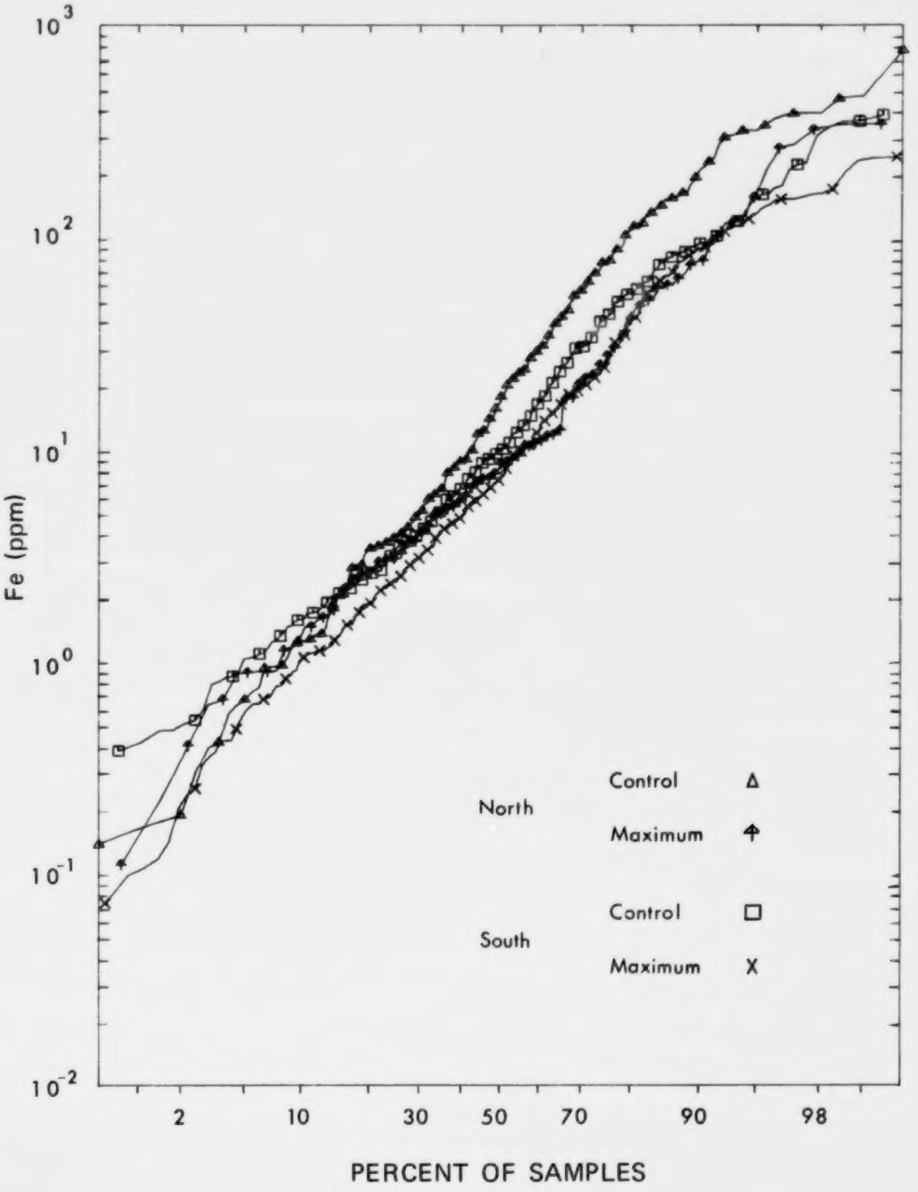

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Figure 50. Frequency distribution of Fe concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

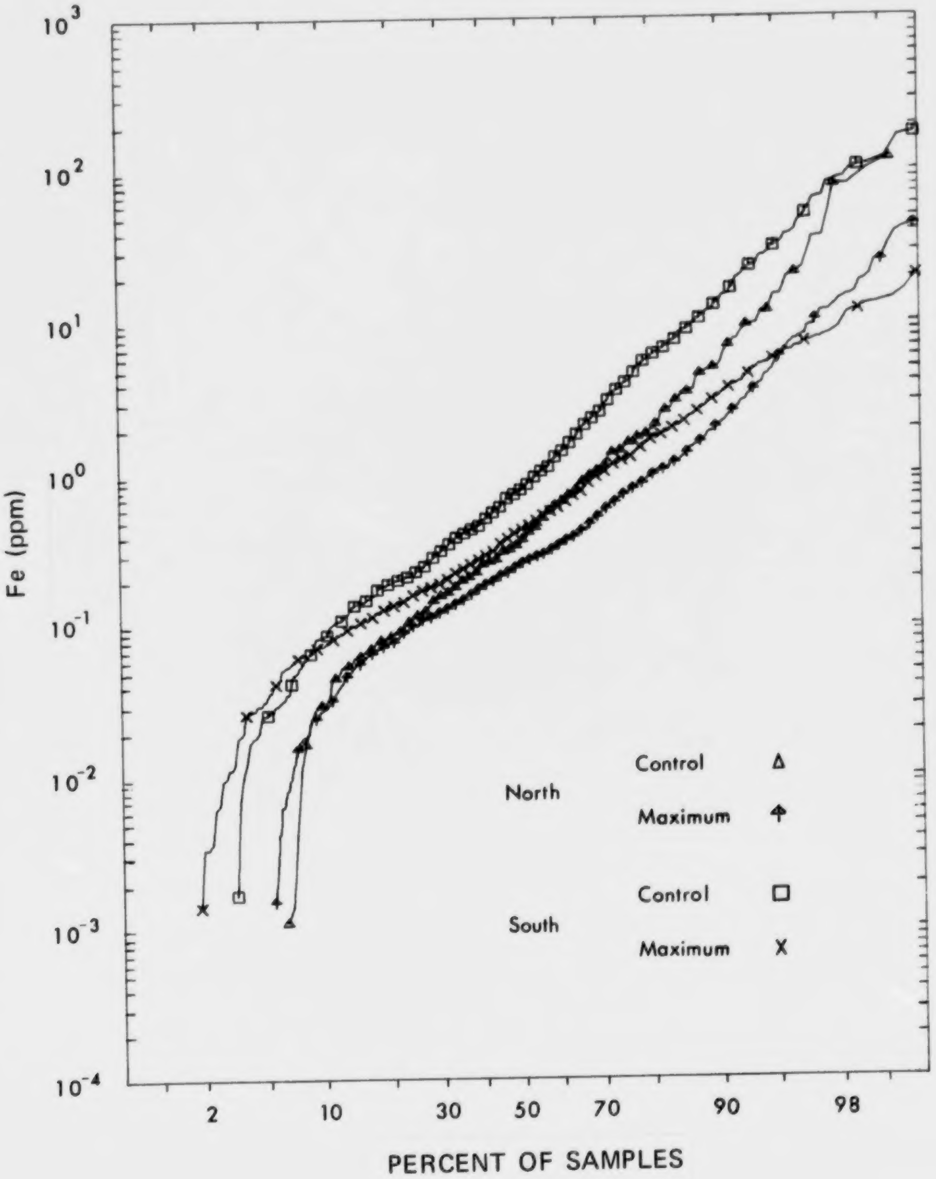

Figure 51. Frequency distribution of Fe concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

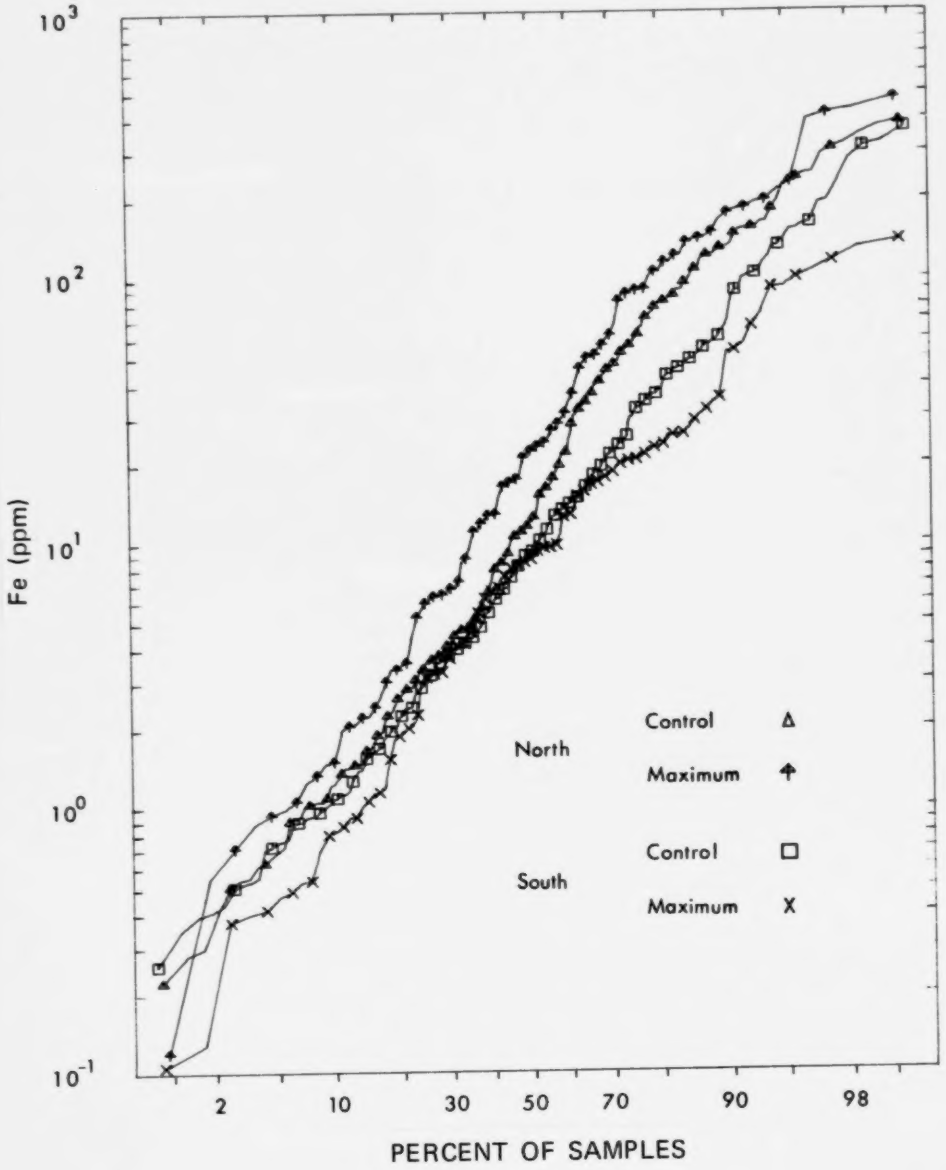

Figure 52. Frequency distribution of Fe concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

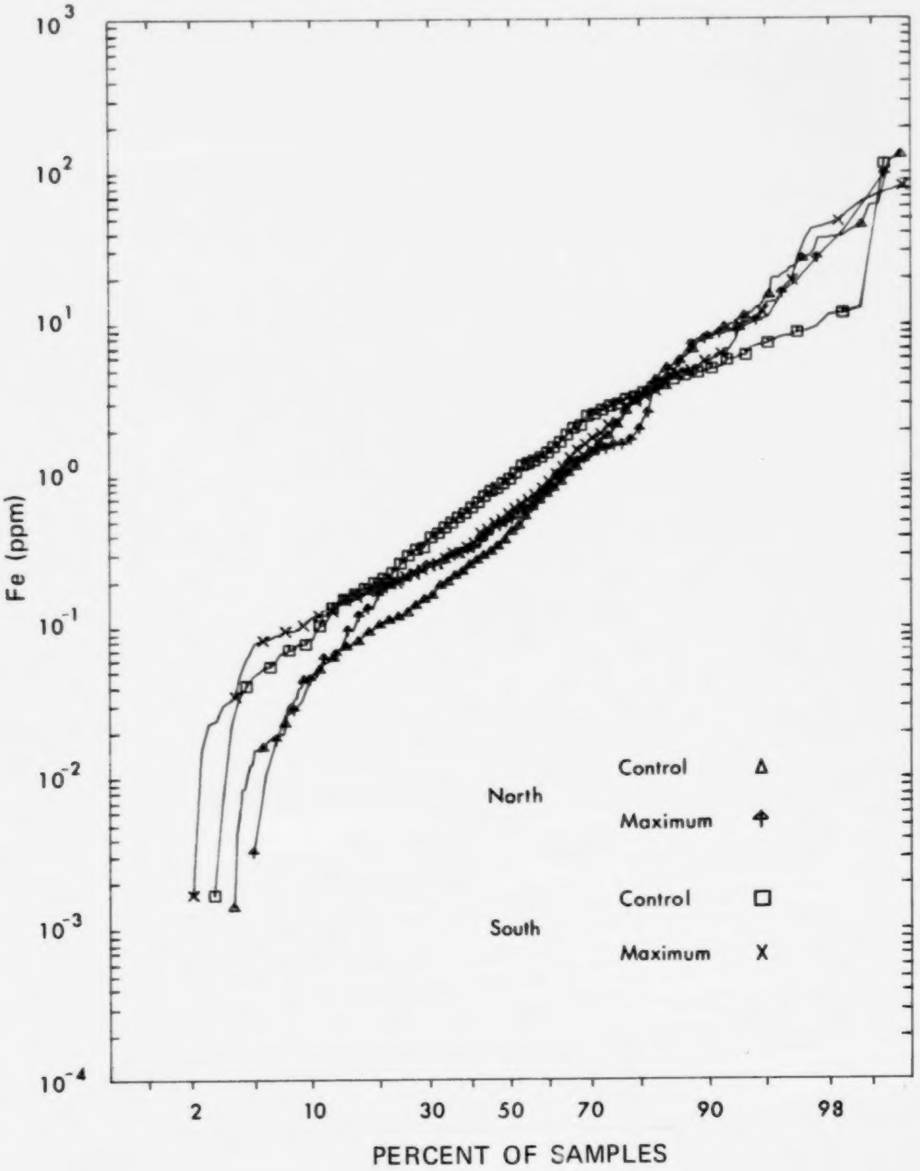

Figure 53. Frequency distribution of Fe concentrations during the period 5/1/72 to 4/30/77in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

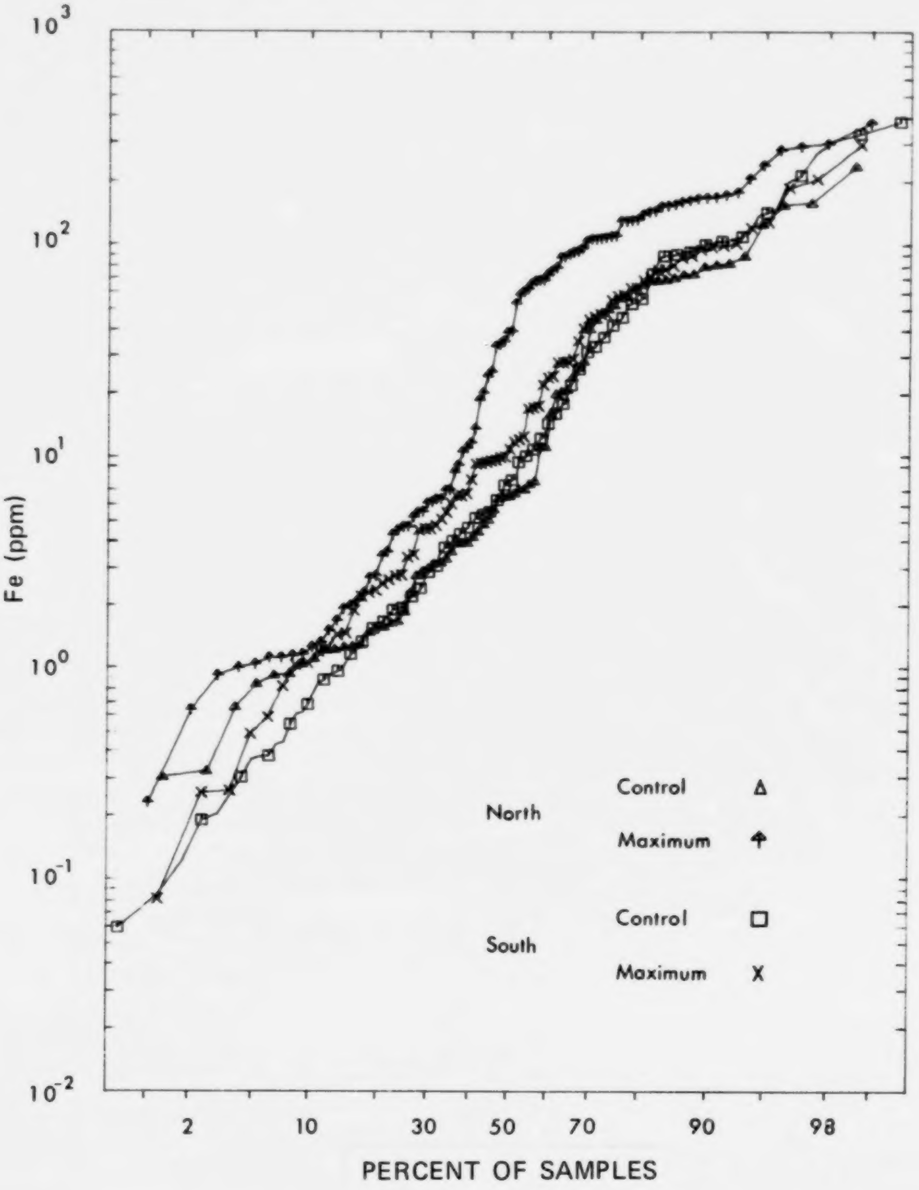

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Figure 54. Frequency distribution of Fe concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

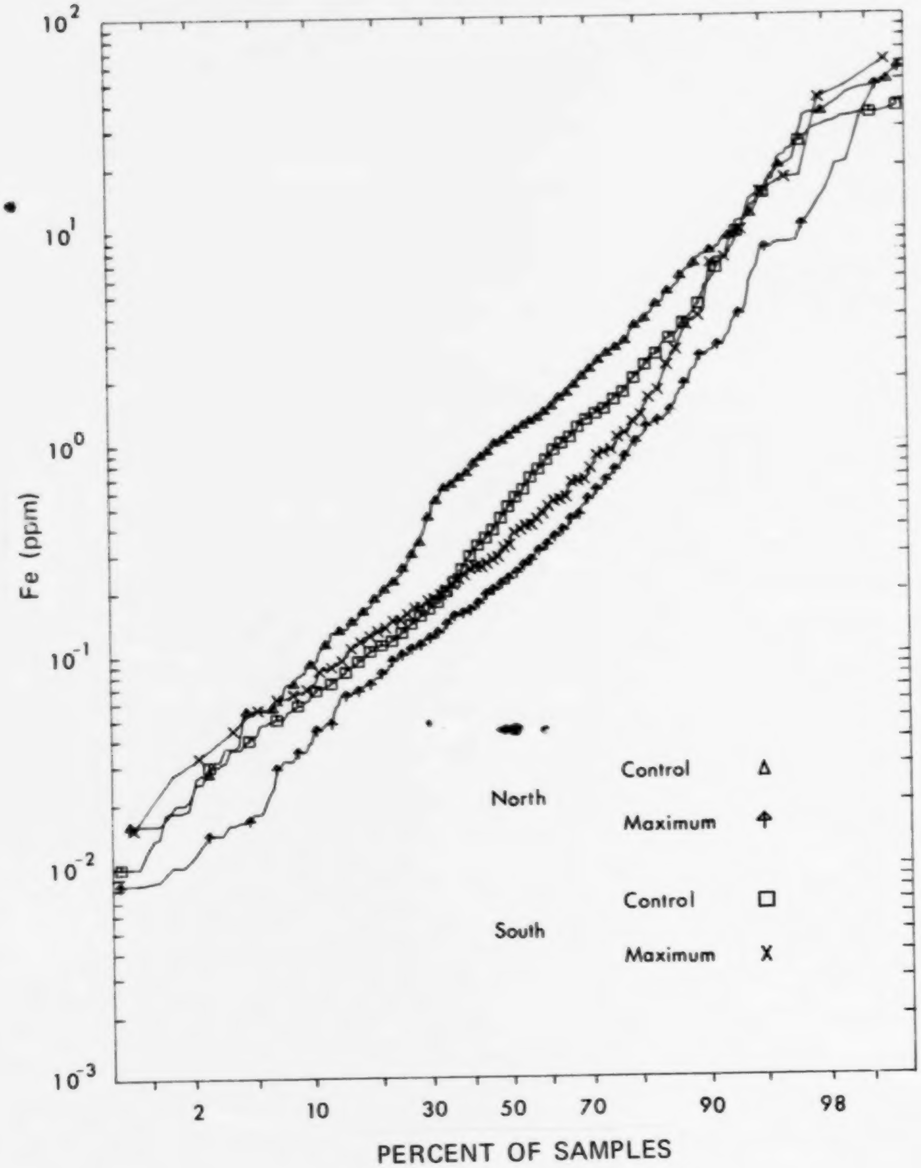

Figure 55. Frequency distribution of Fe concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Fe concentrations are percent of samples containing less than amounts shown on the vertical axis.

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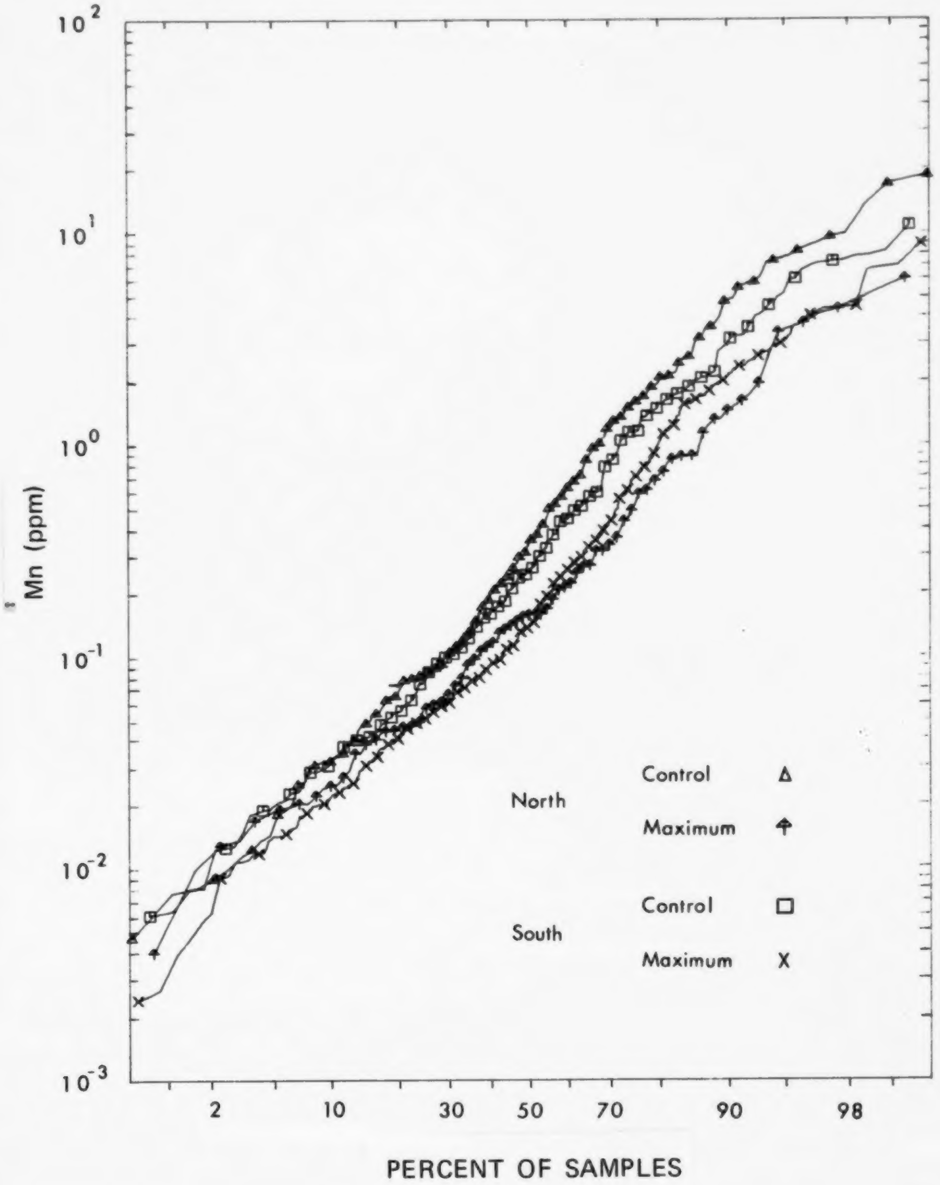

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Figure 56. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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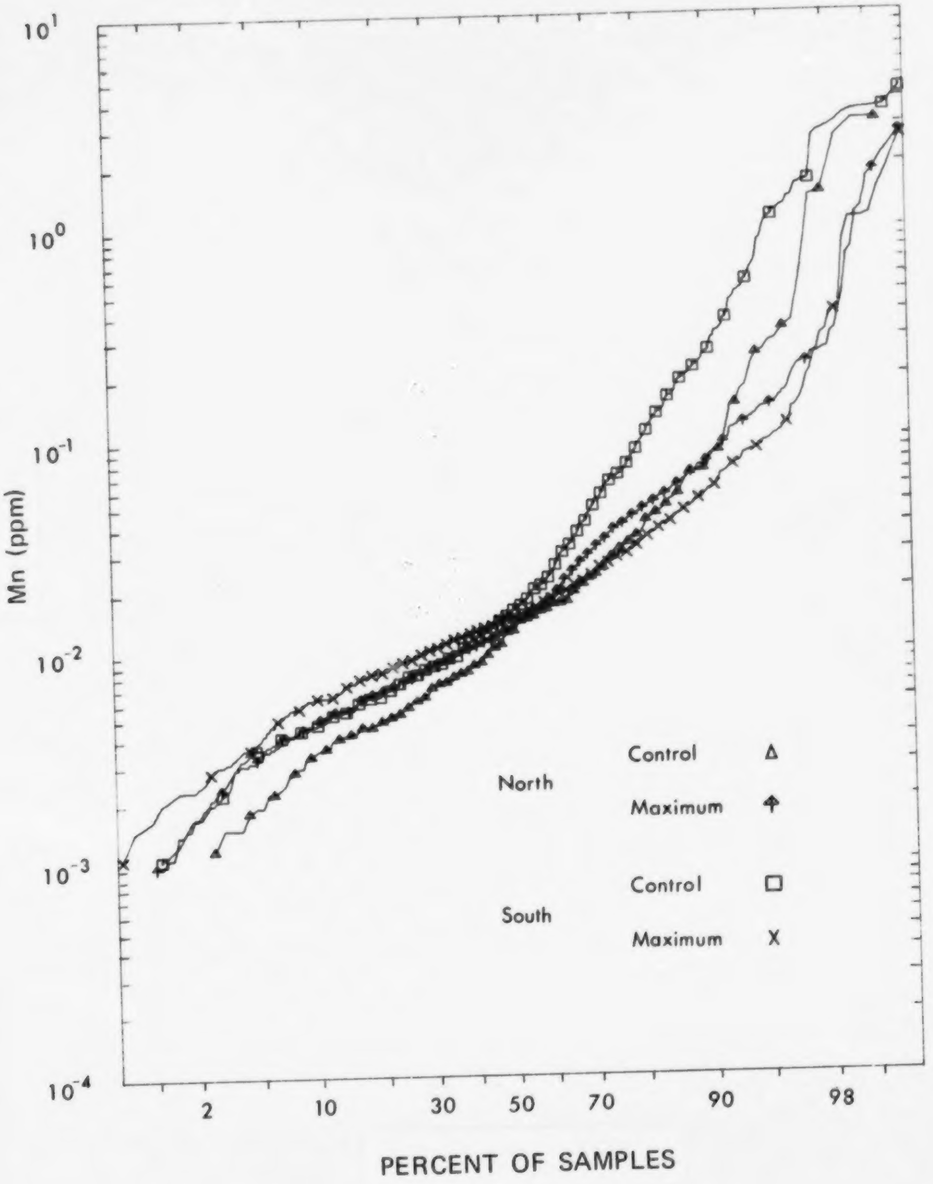

Figure 57. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

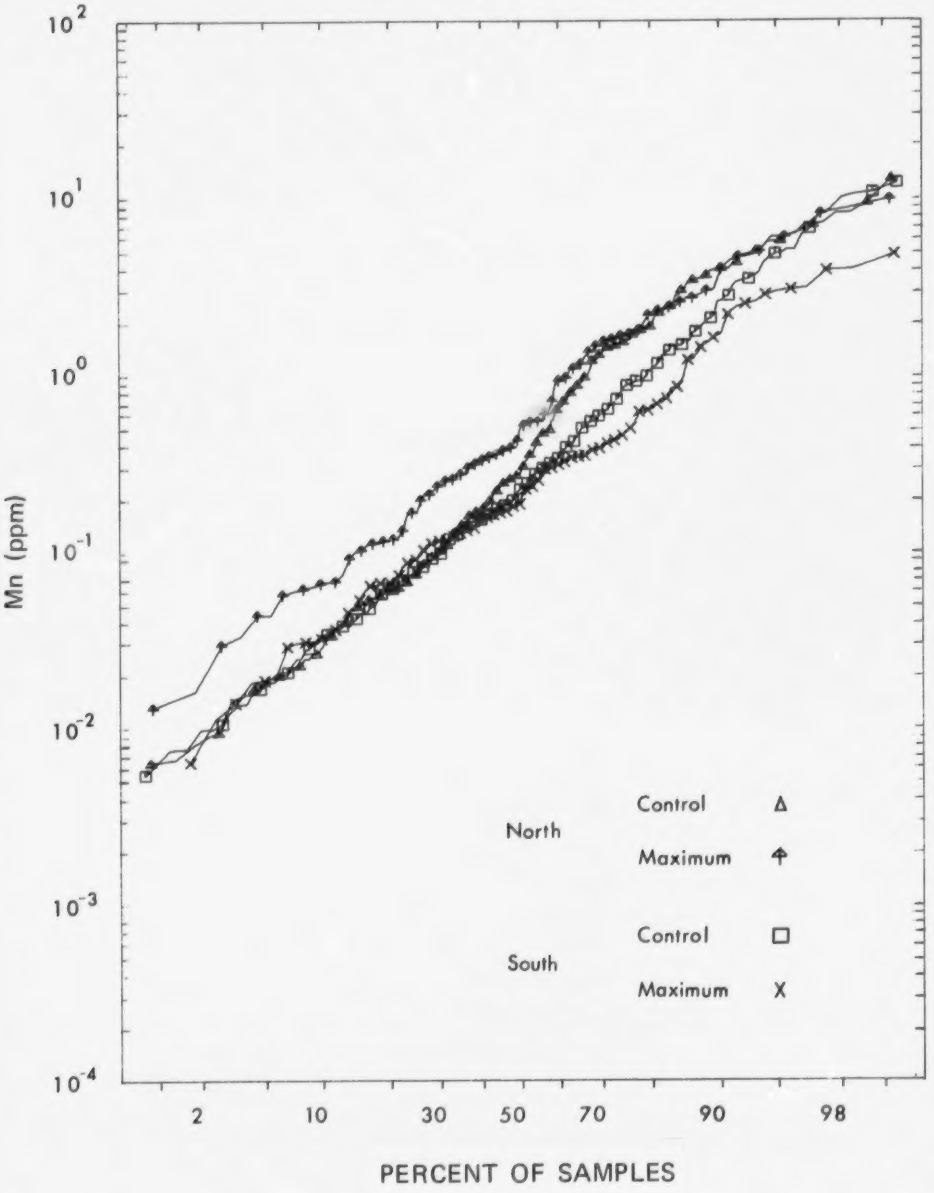

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Figure 58. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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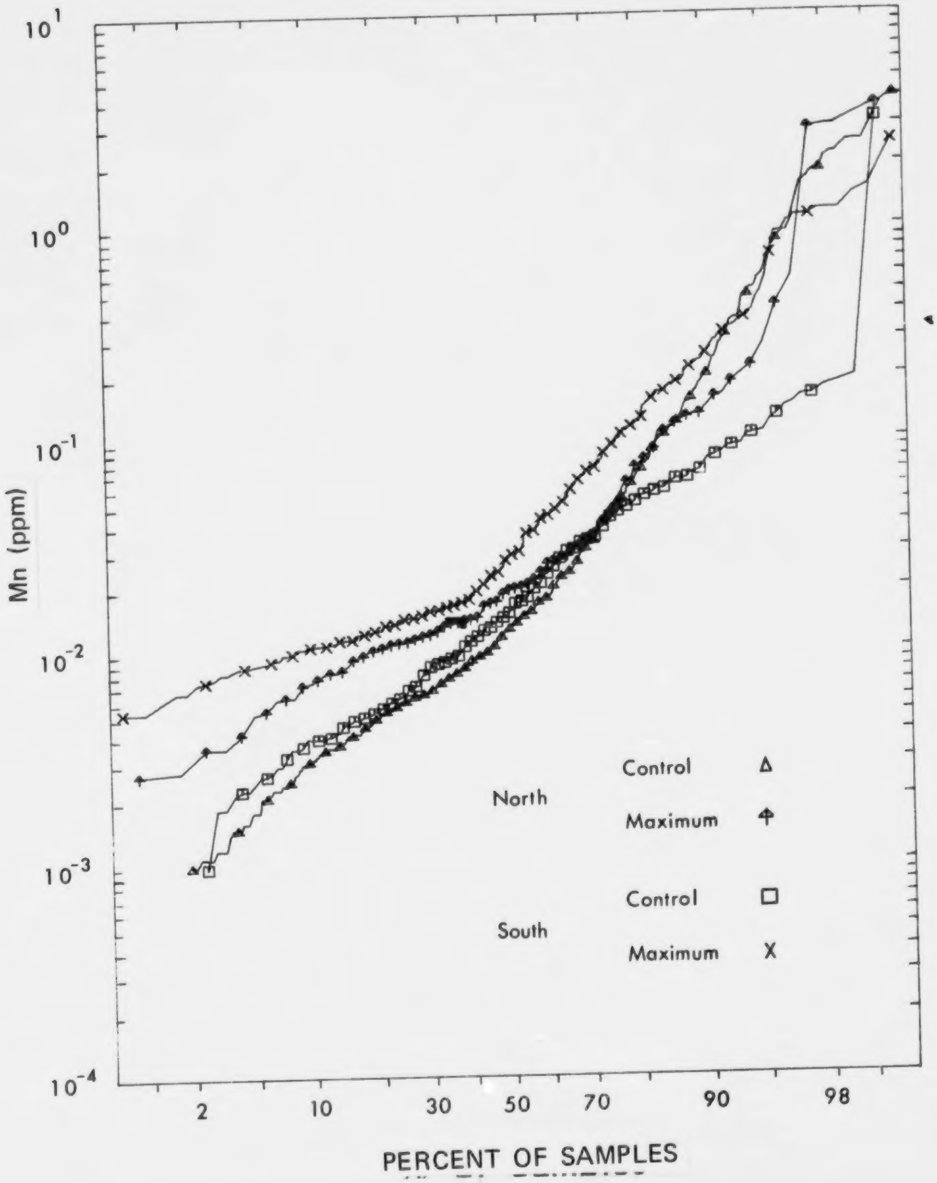

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Figure 59. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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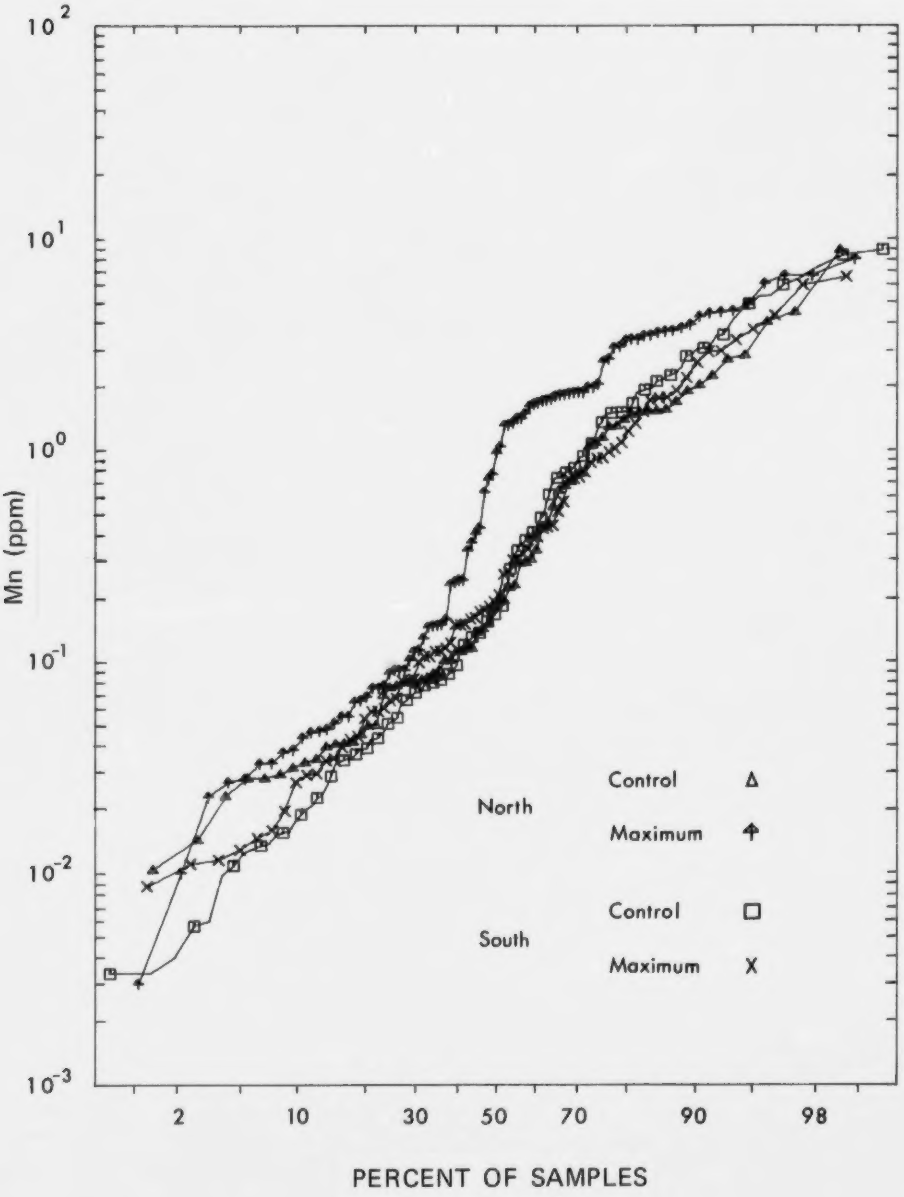

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Figure 60. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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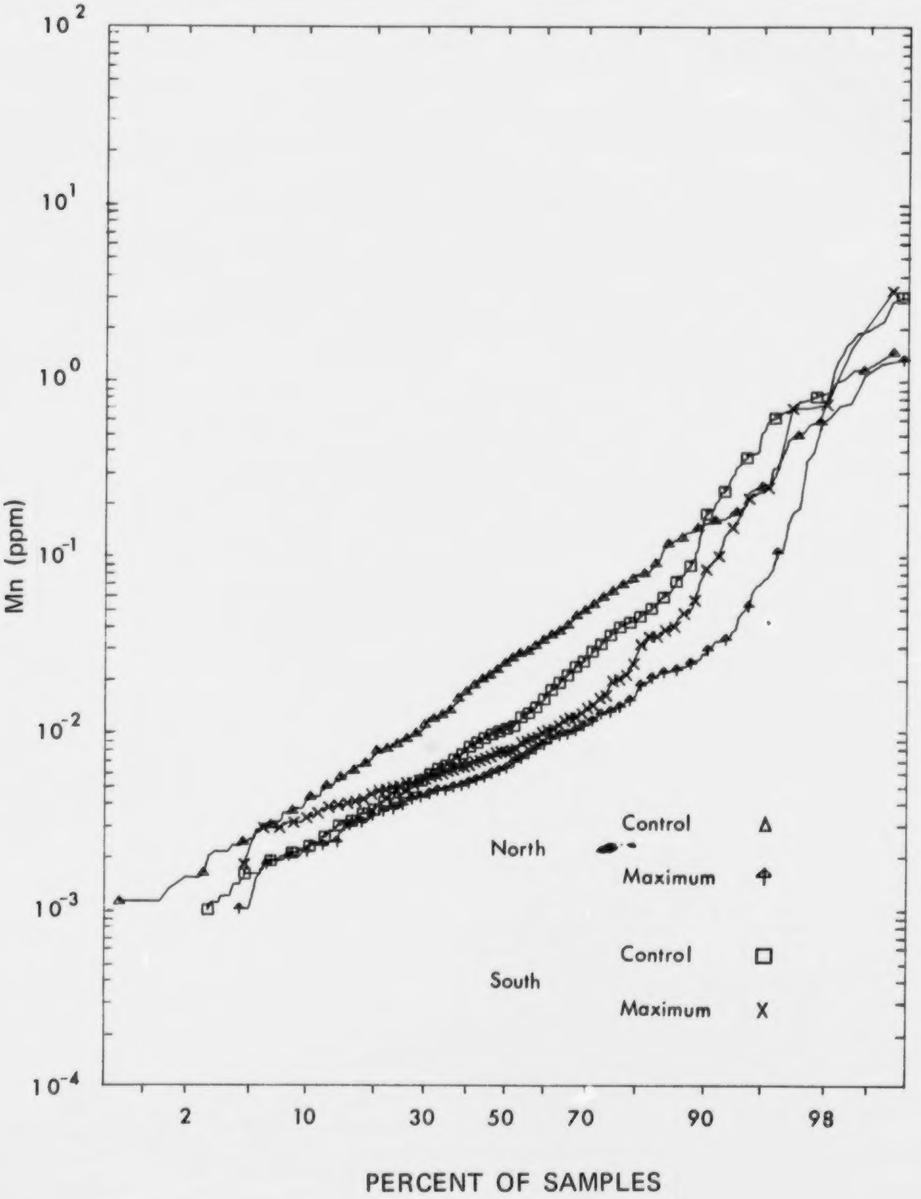

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Figure 61. Frequency distribution of Mn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Mn concentrations are percent of samples containing less than amounts shown on the vertical axis.

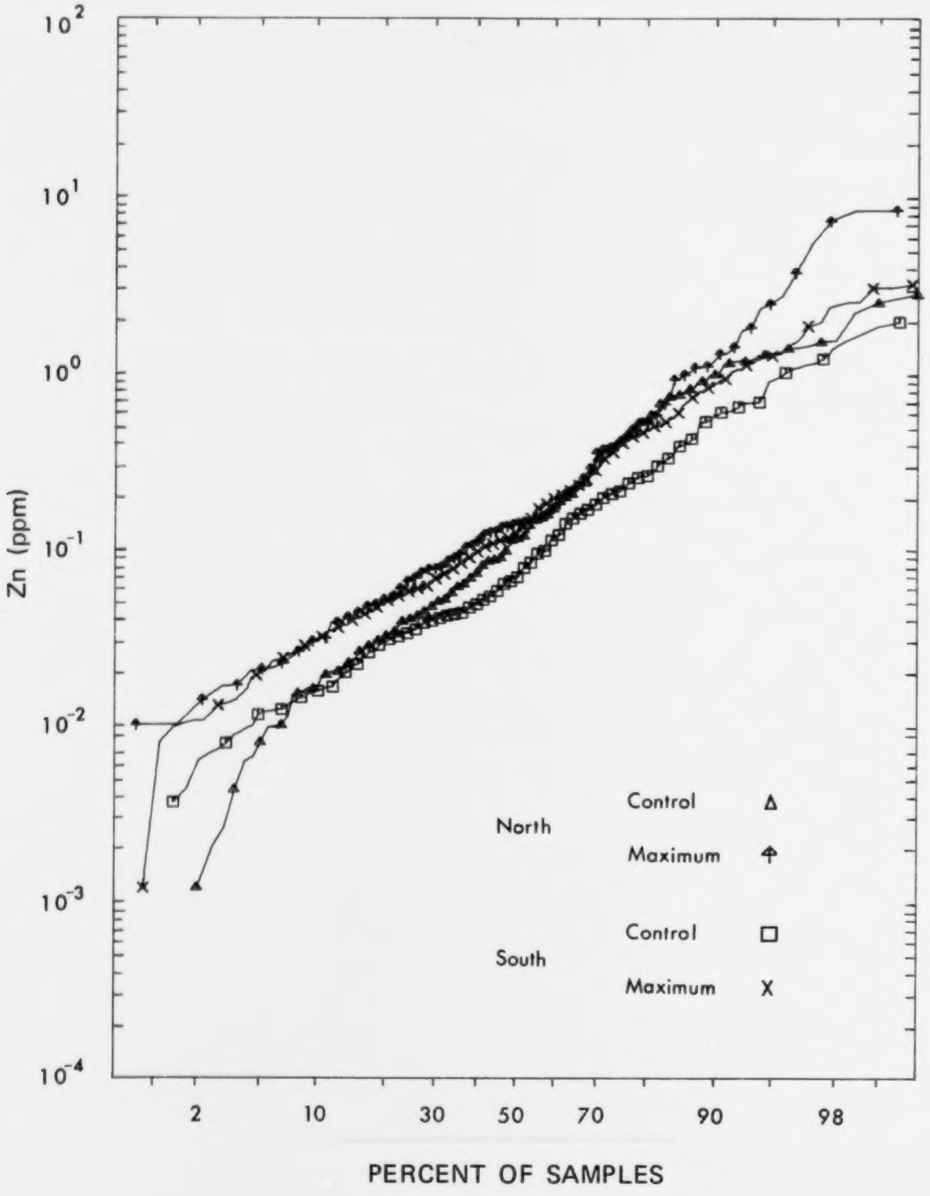

Figure 62. Frequency distribution of Zn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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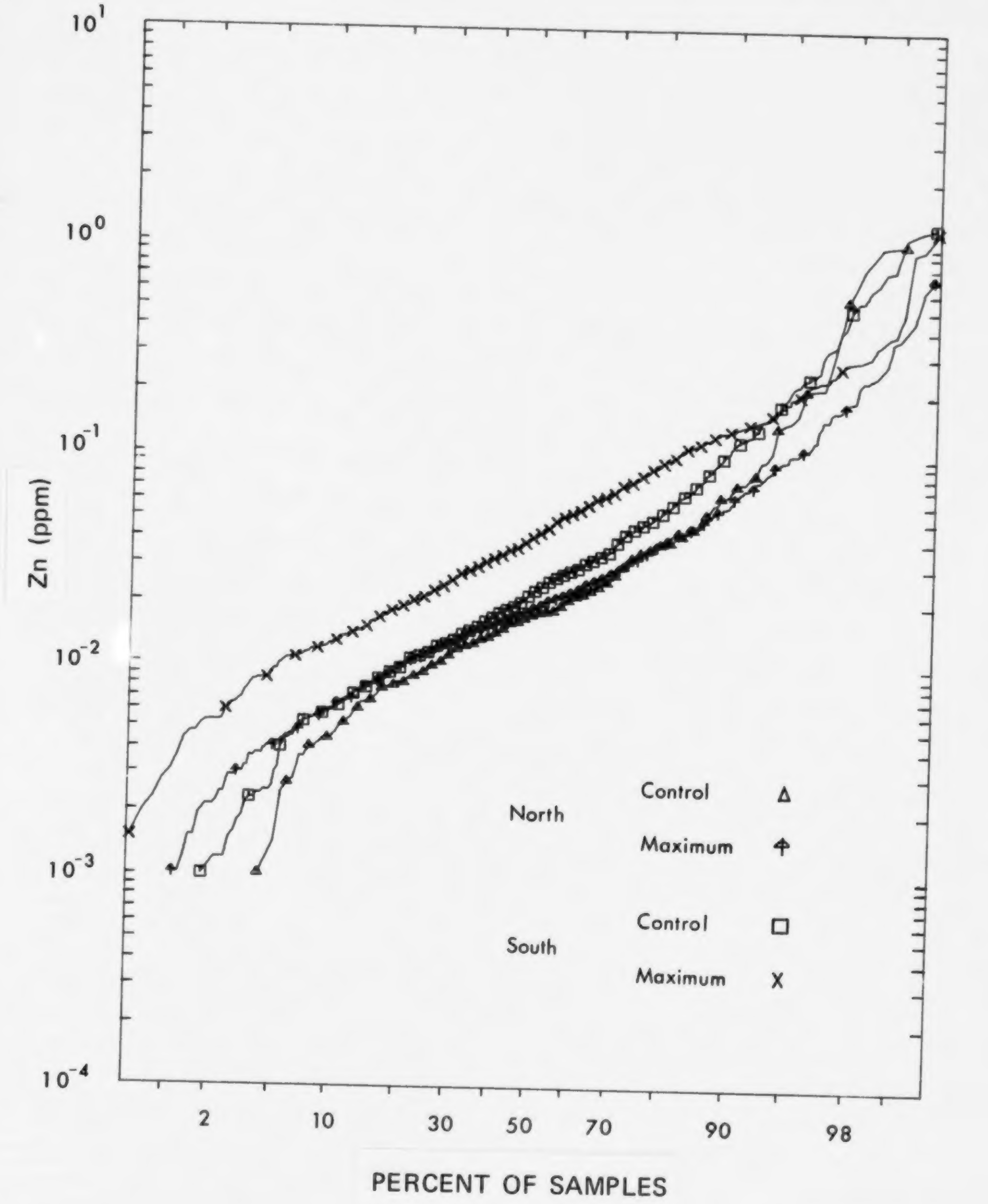

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Figure 63. Frequency distribution of Zn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

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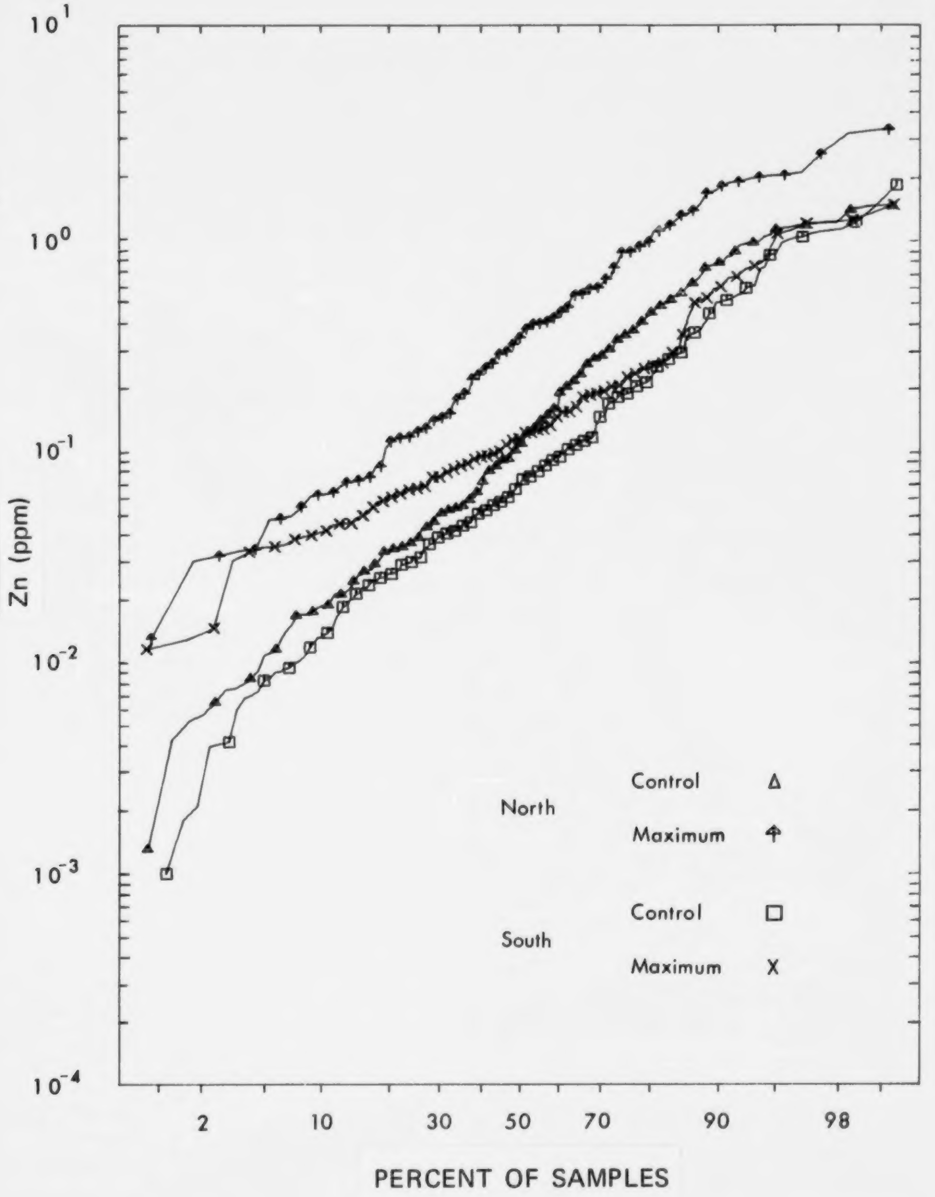

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Figure 64. Frequency distribution of Zn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

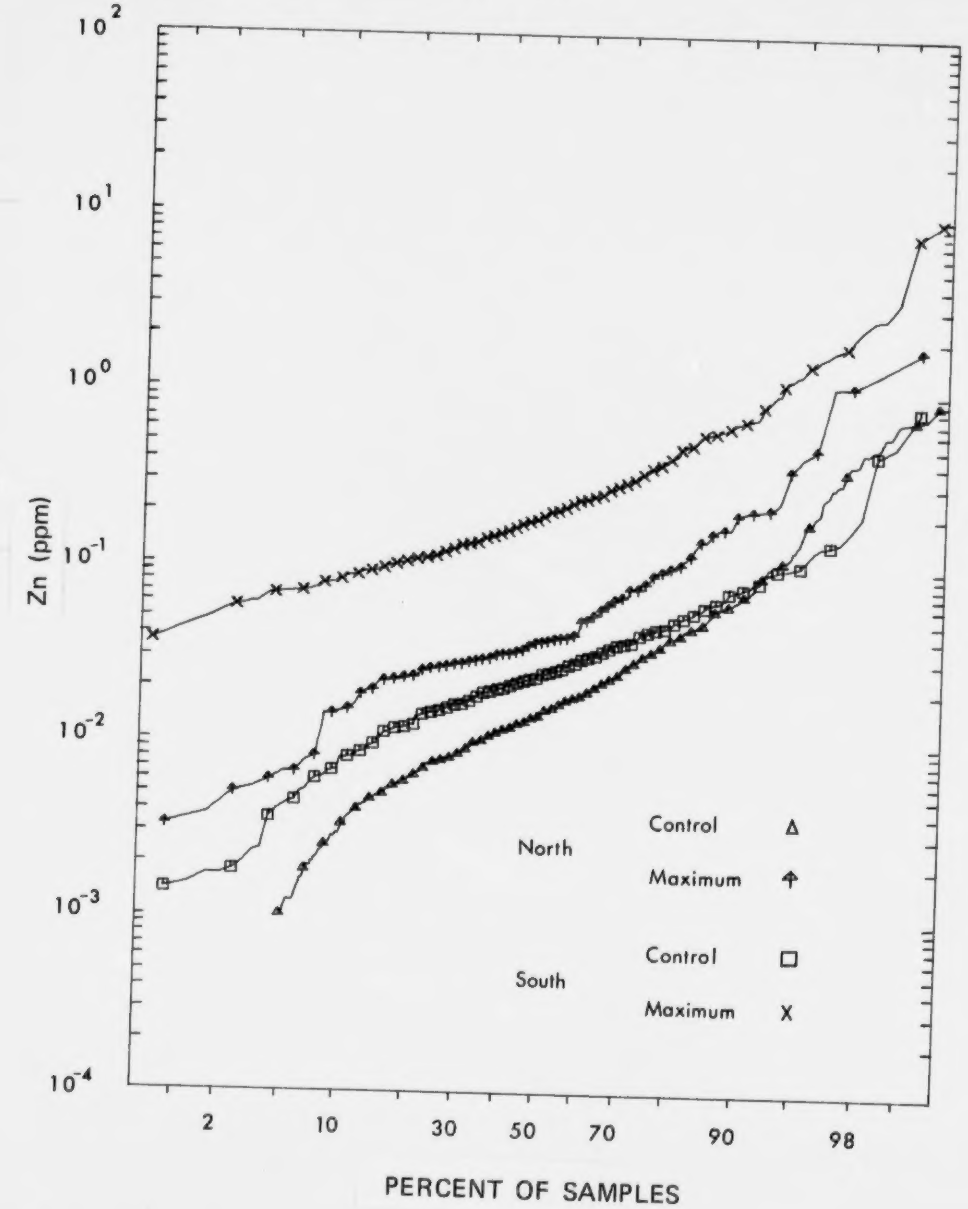

Figure 65. Frequency distribution of Zn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

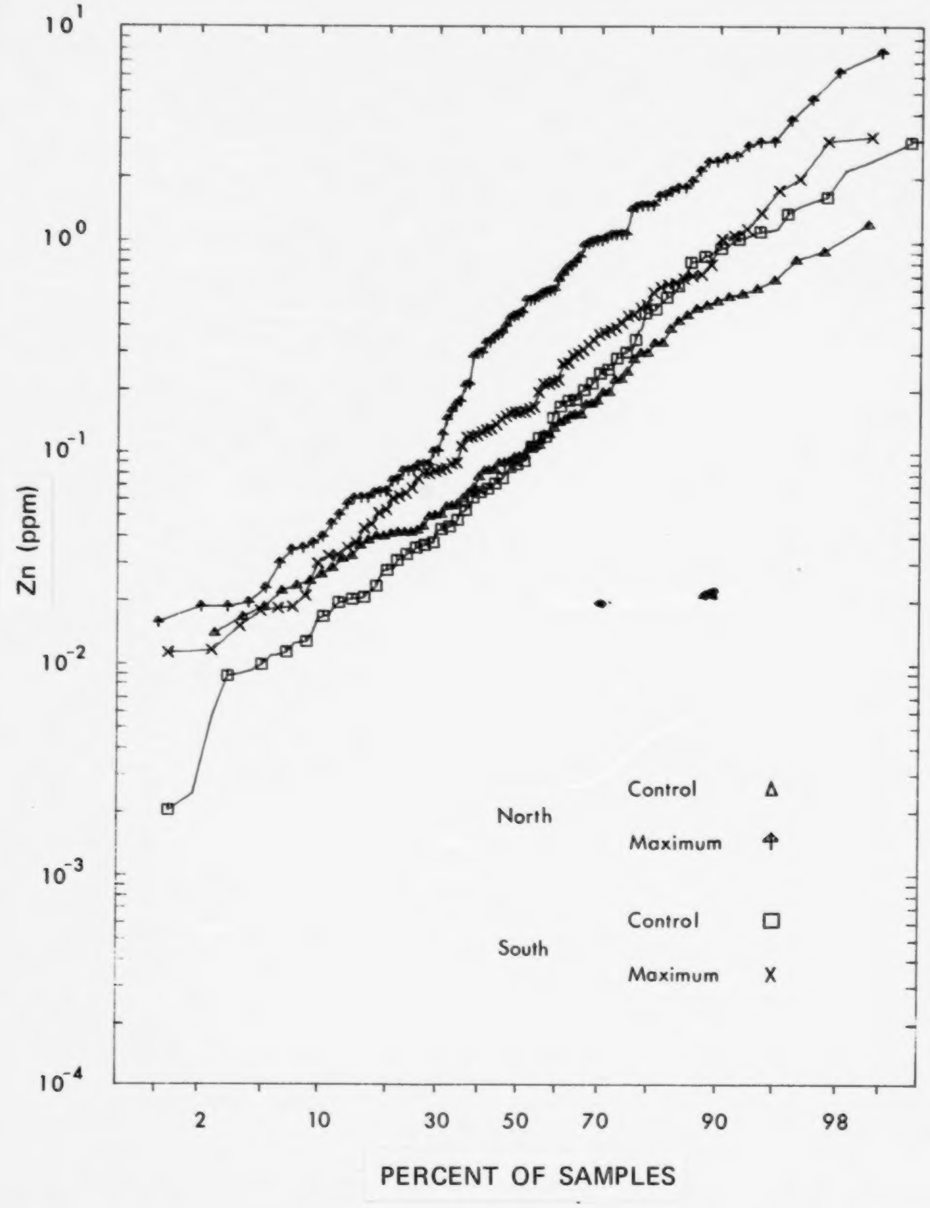

Figure 66. Frequency distribution of Zn concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

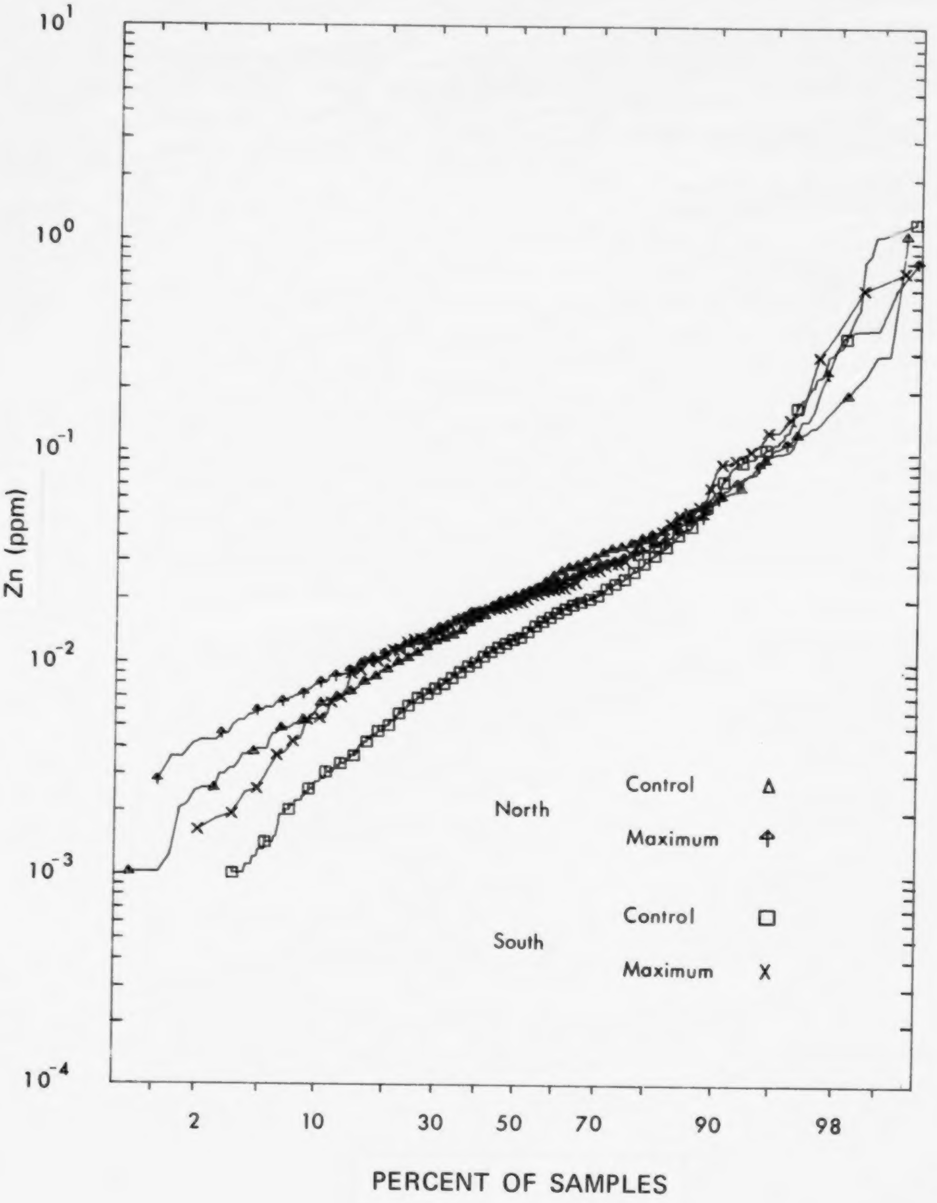

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Figure 67. Frequency distributions of Zn concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Zn concentrations are percent of samples containing less than amounts shown on the vertical axis.

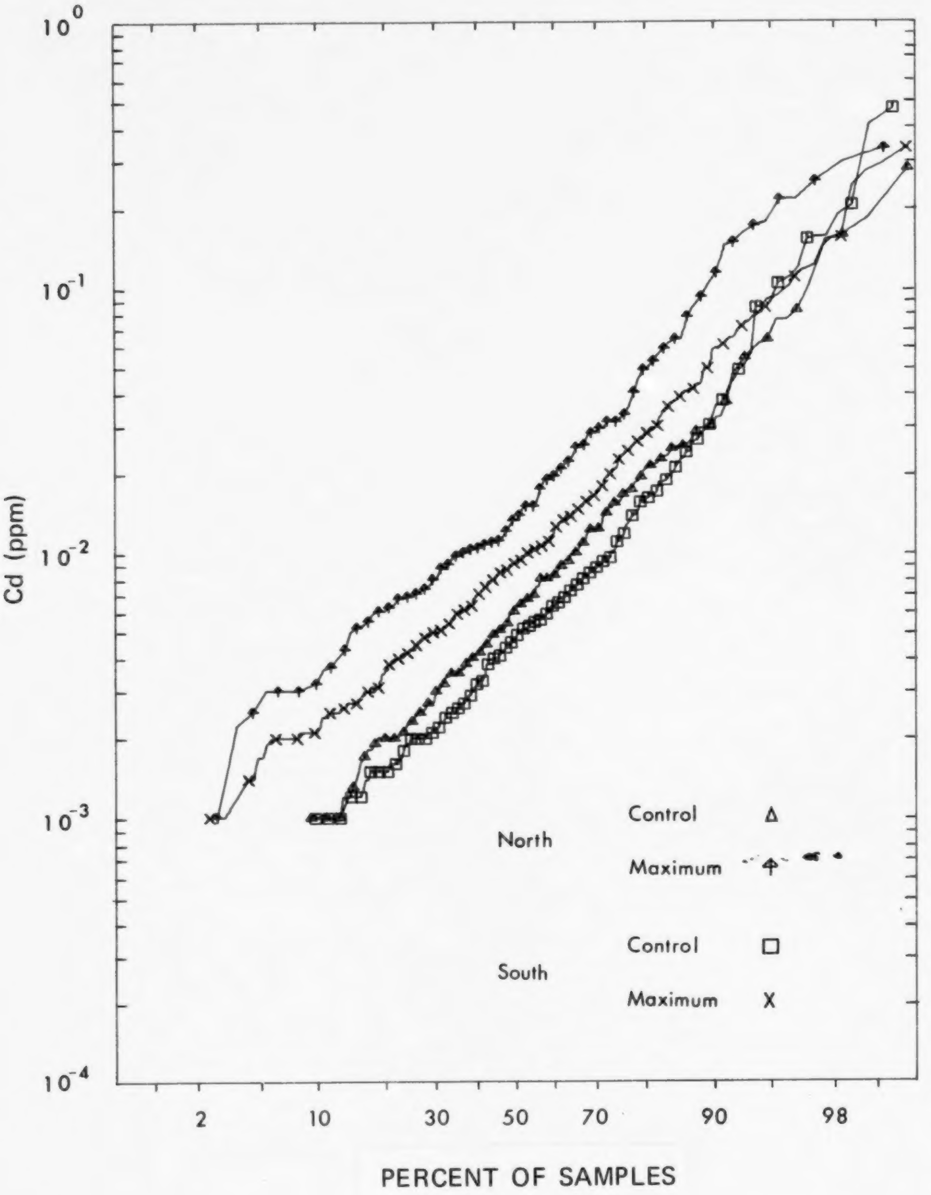

Figure 68. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

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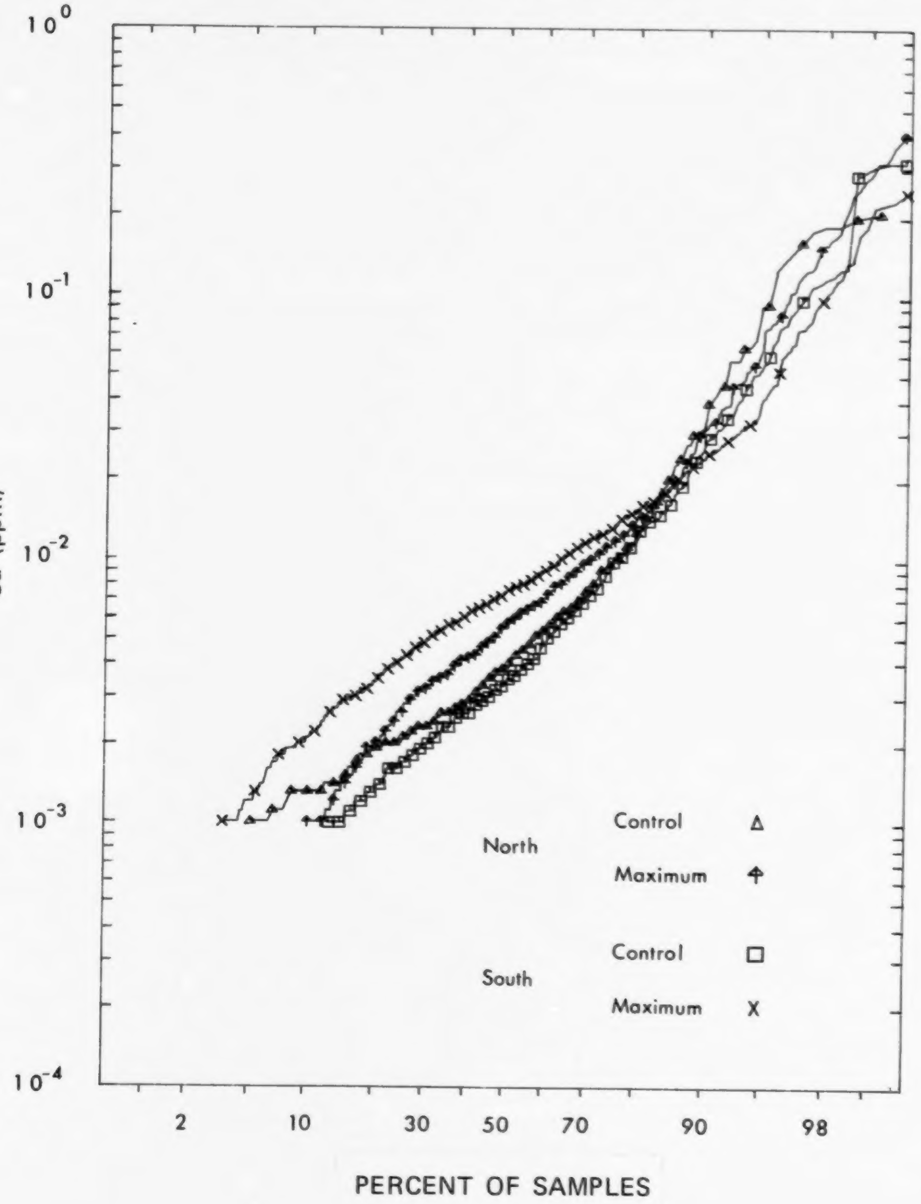

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Figure 69. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

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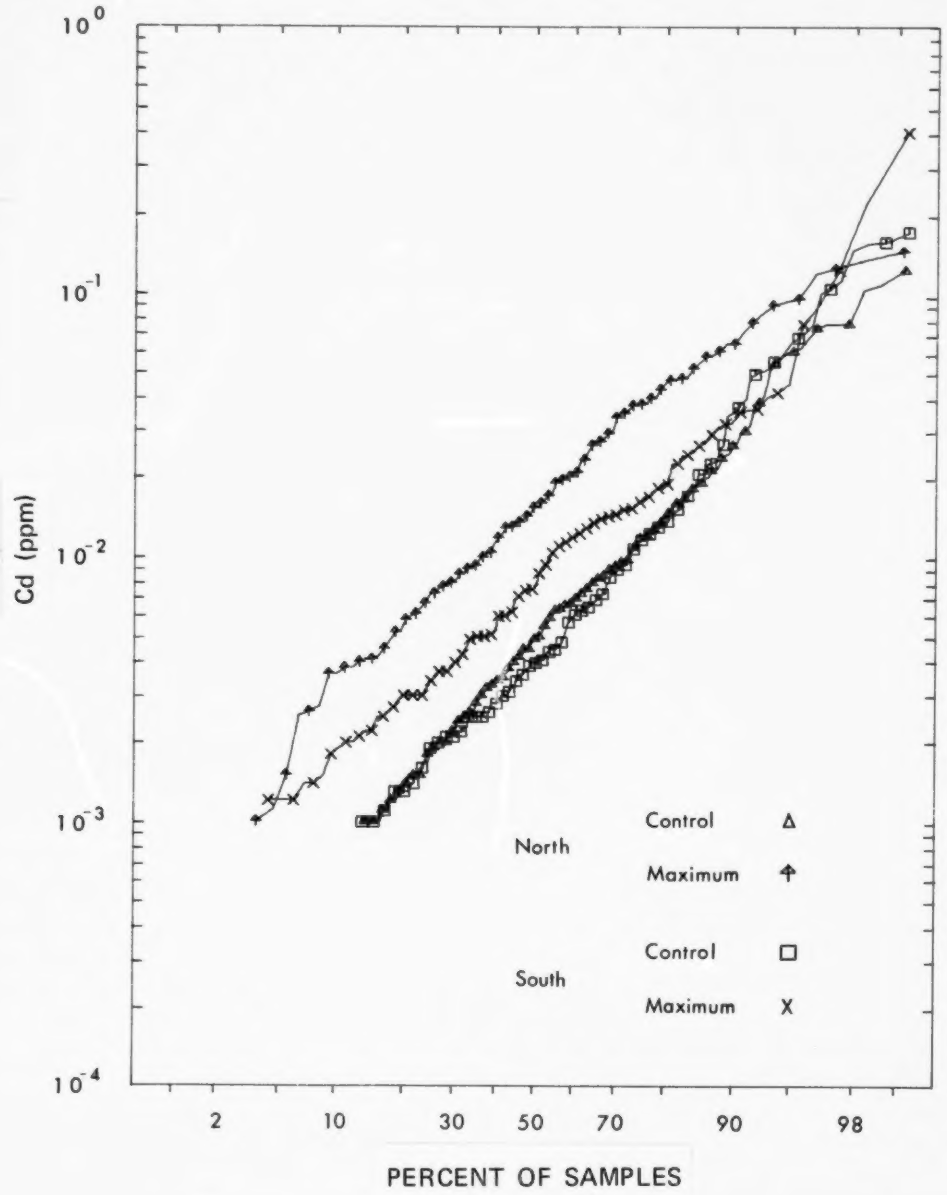

Figure 70. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

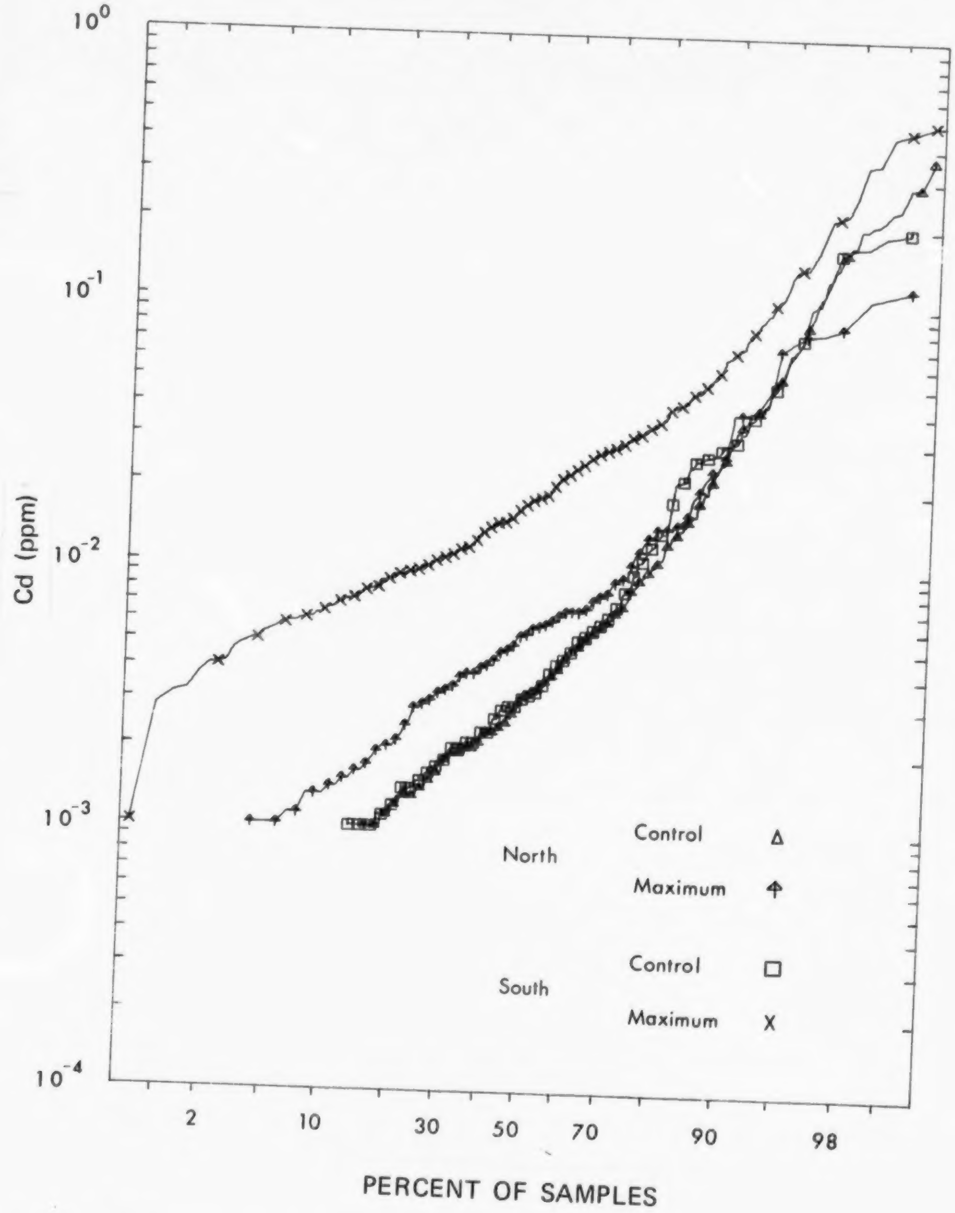

Figure 71. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

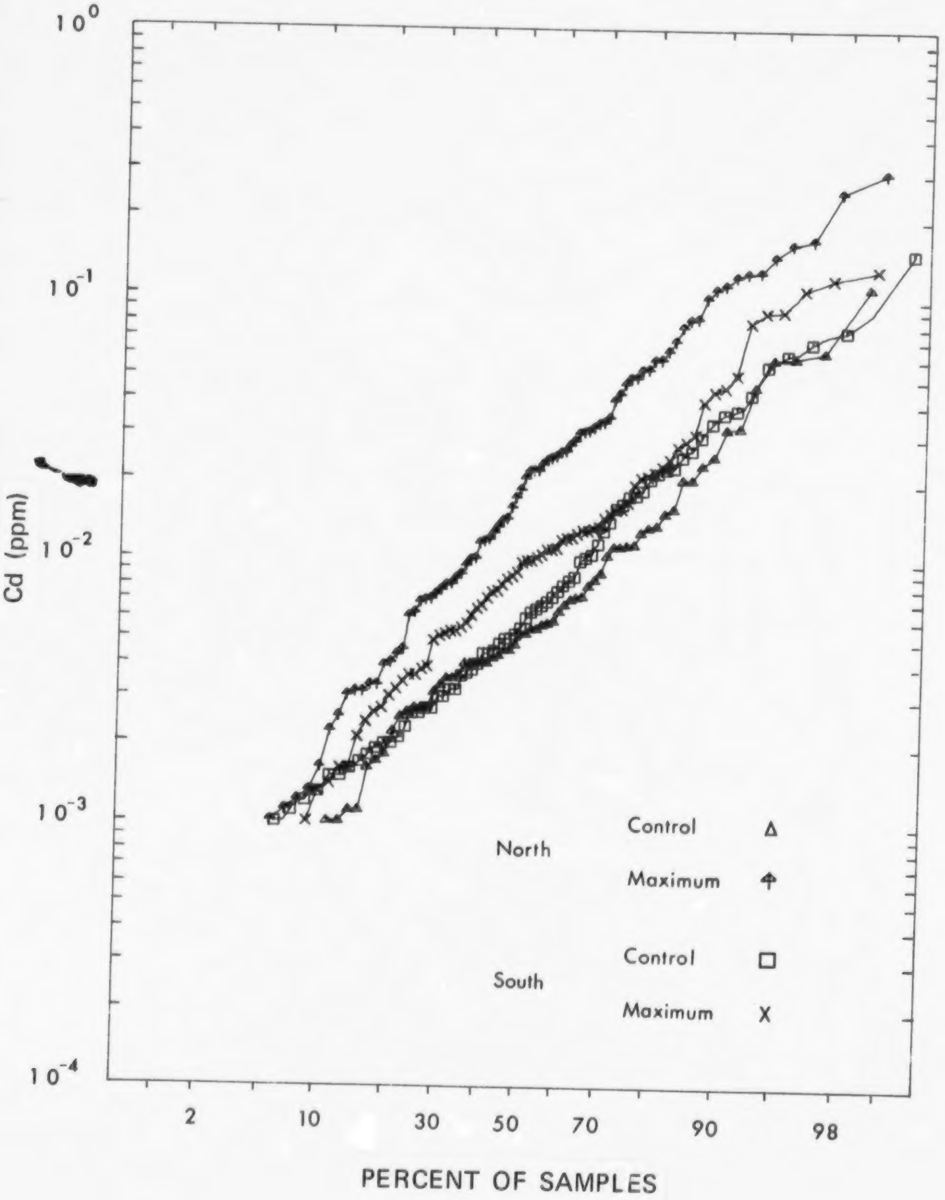

Figure 72. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

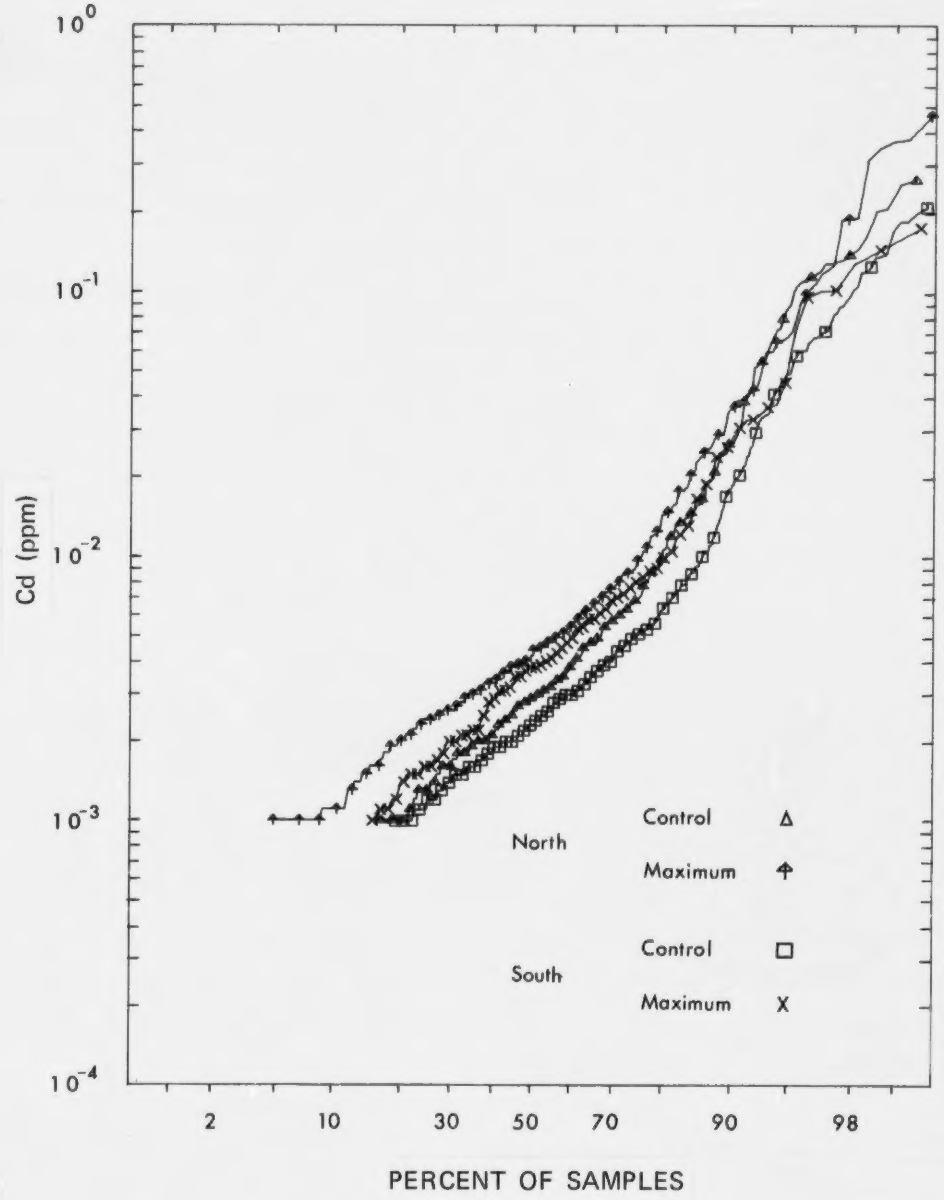

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Figure 73. Frequency distribution of Cd concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Cd concentrations are percent of samples containing less than amounts shown on the vertical axis.

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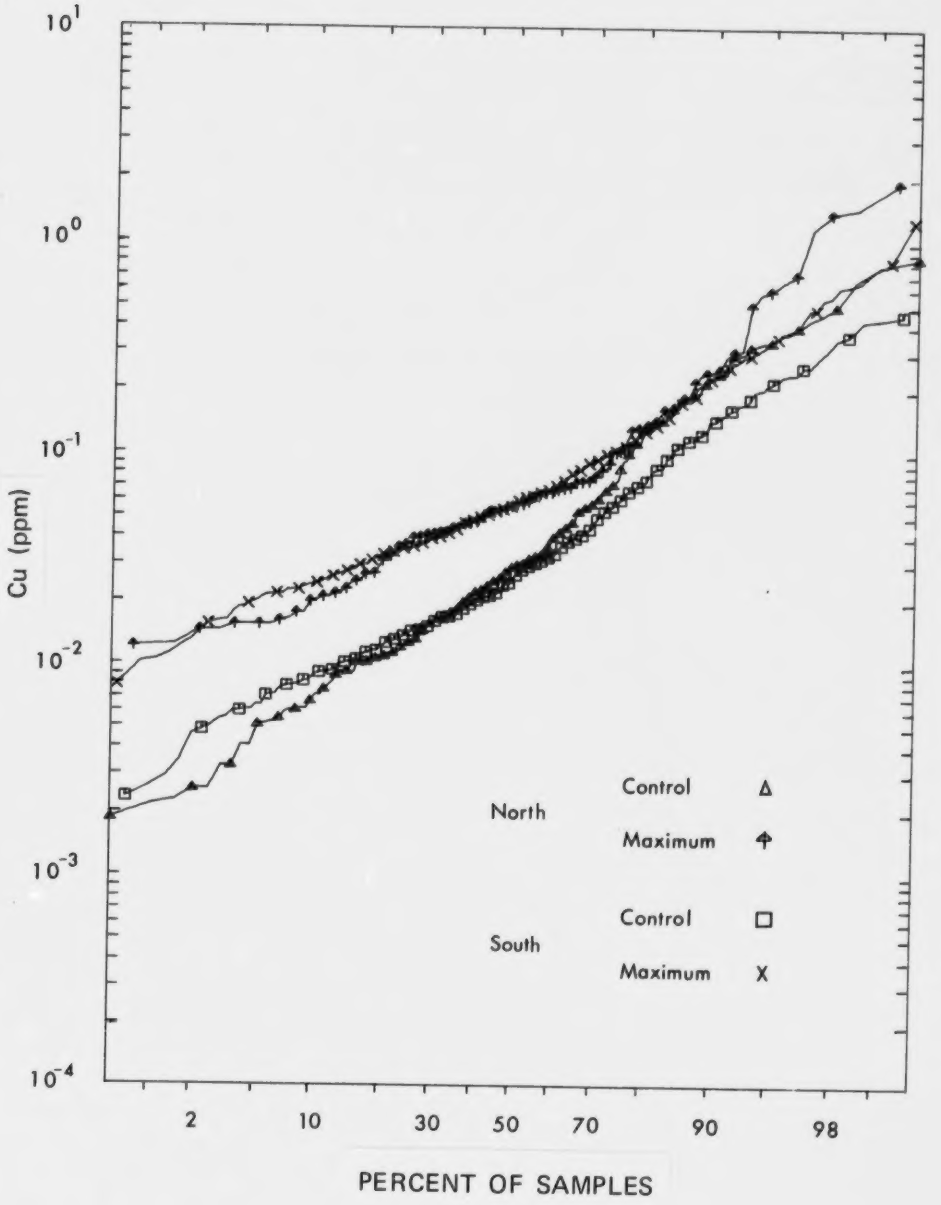

Figure 74. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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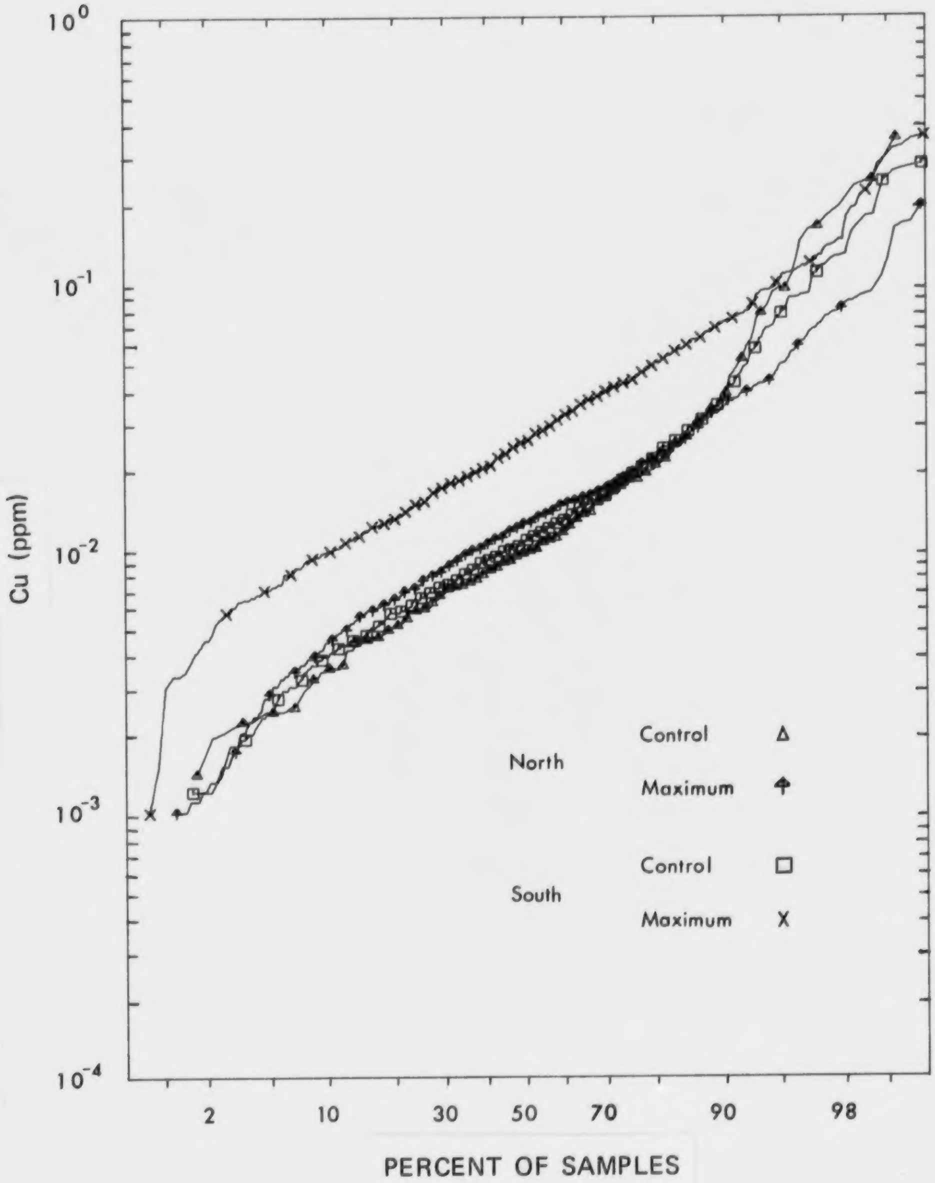

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Figure 75. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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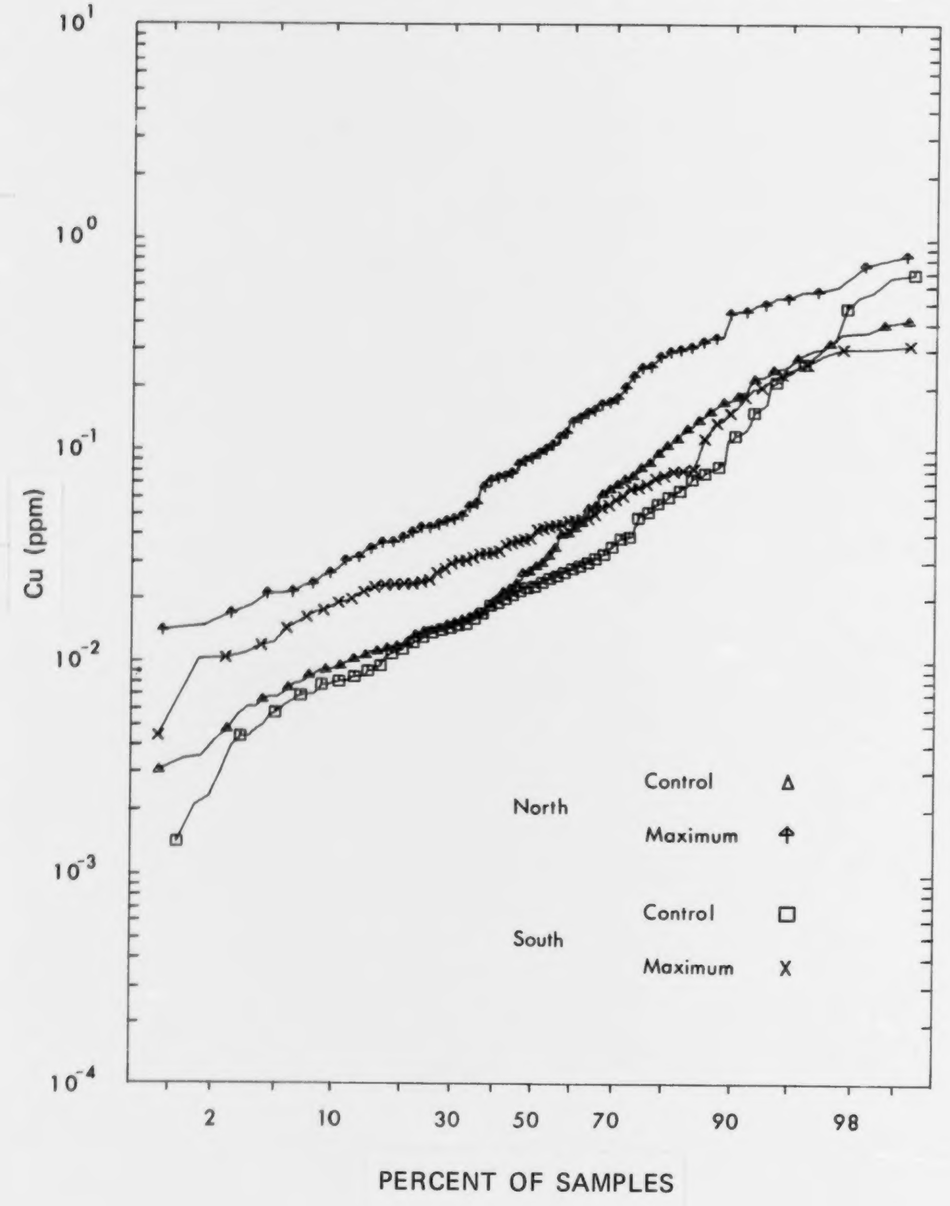

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Figure 76. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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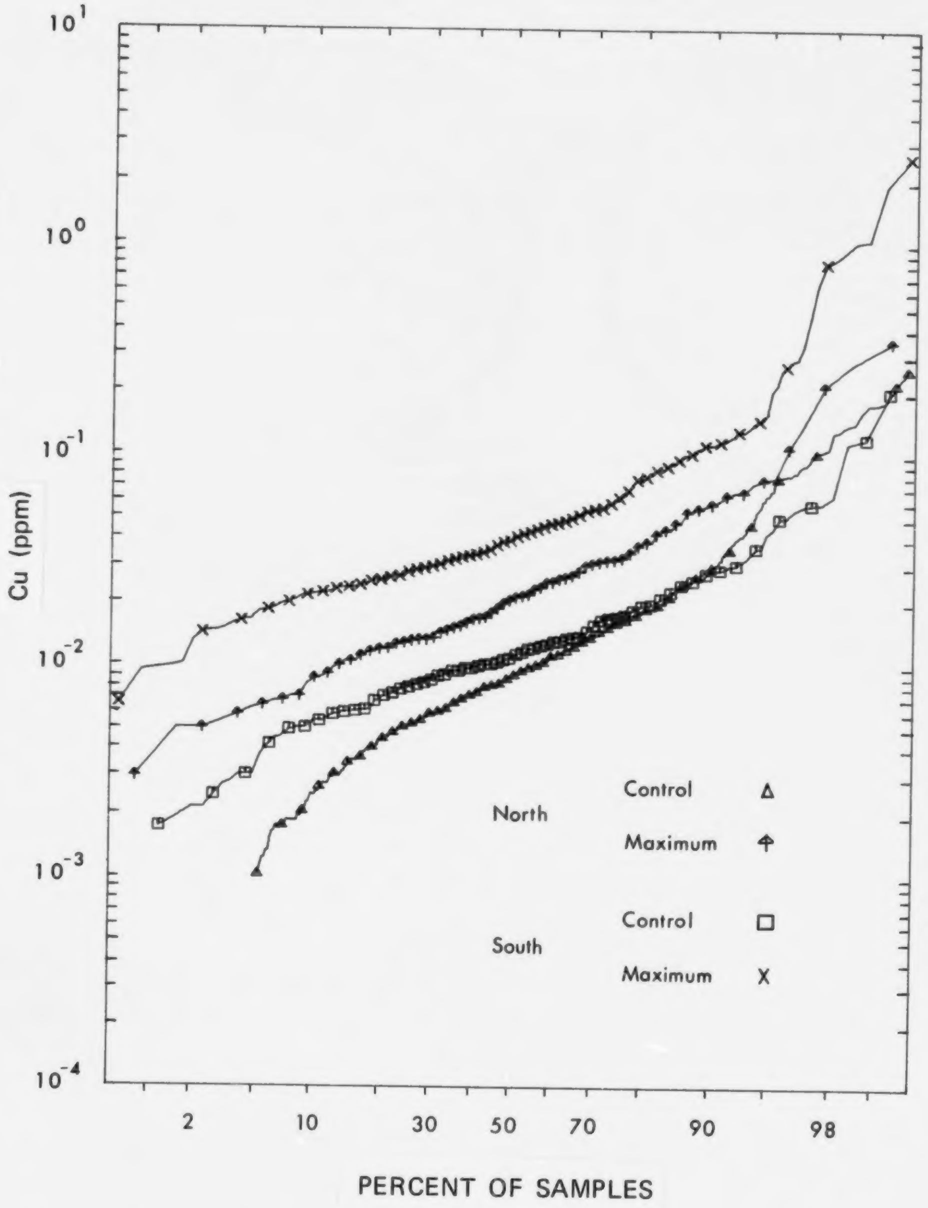

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Figure 77. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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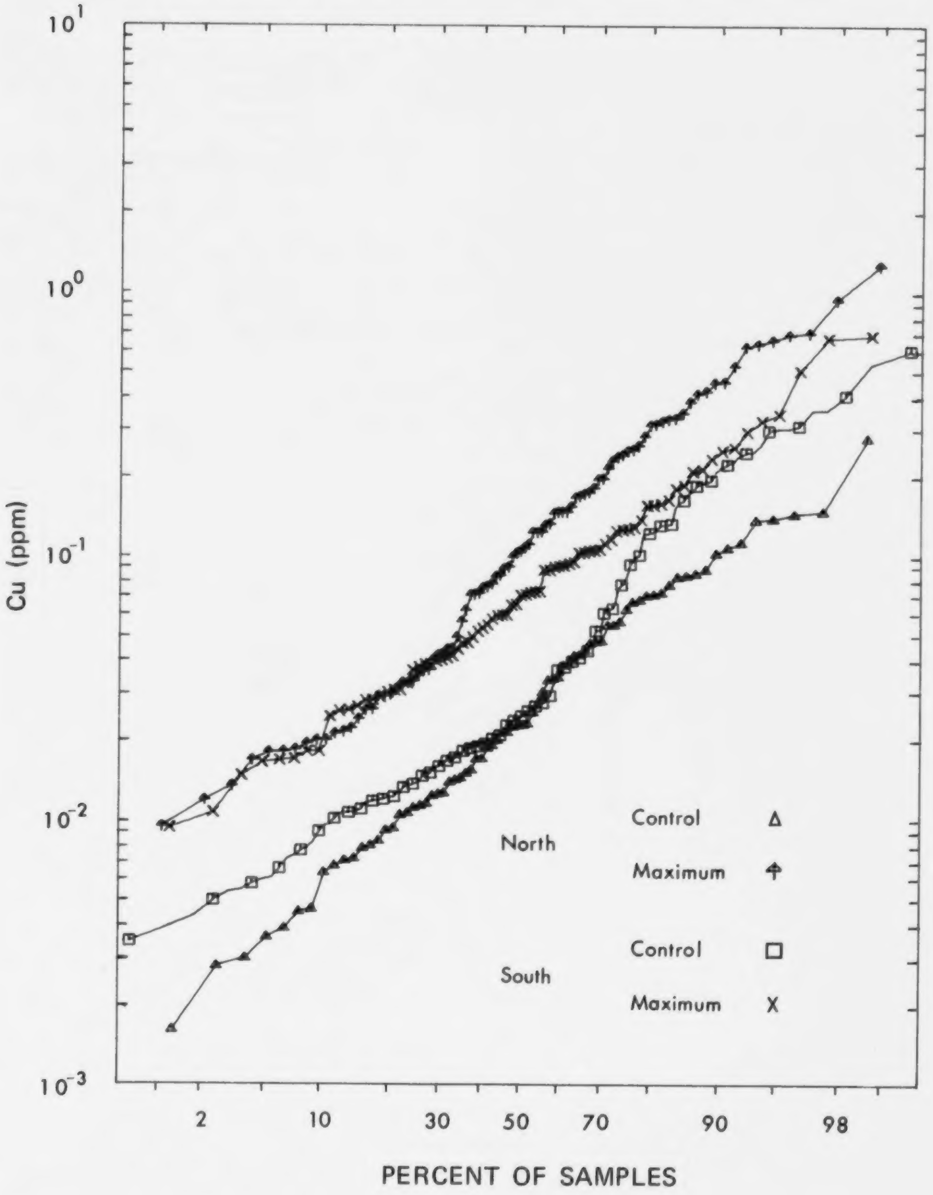

Figure 78. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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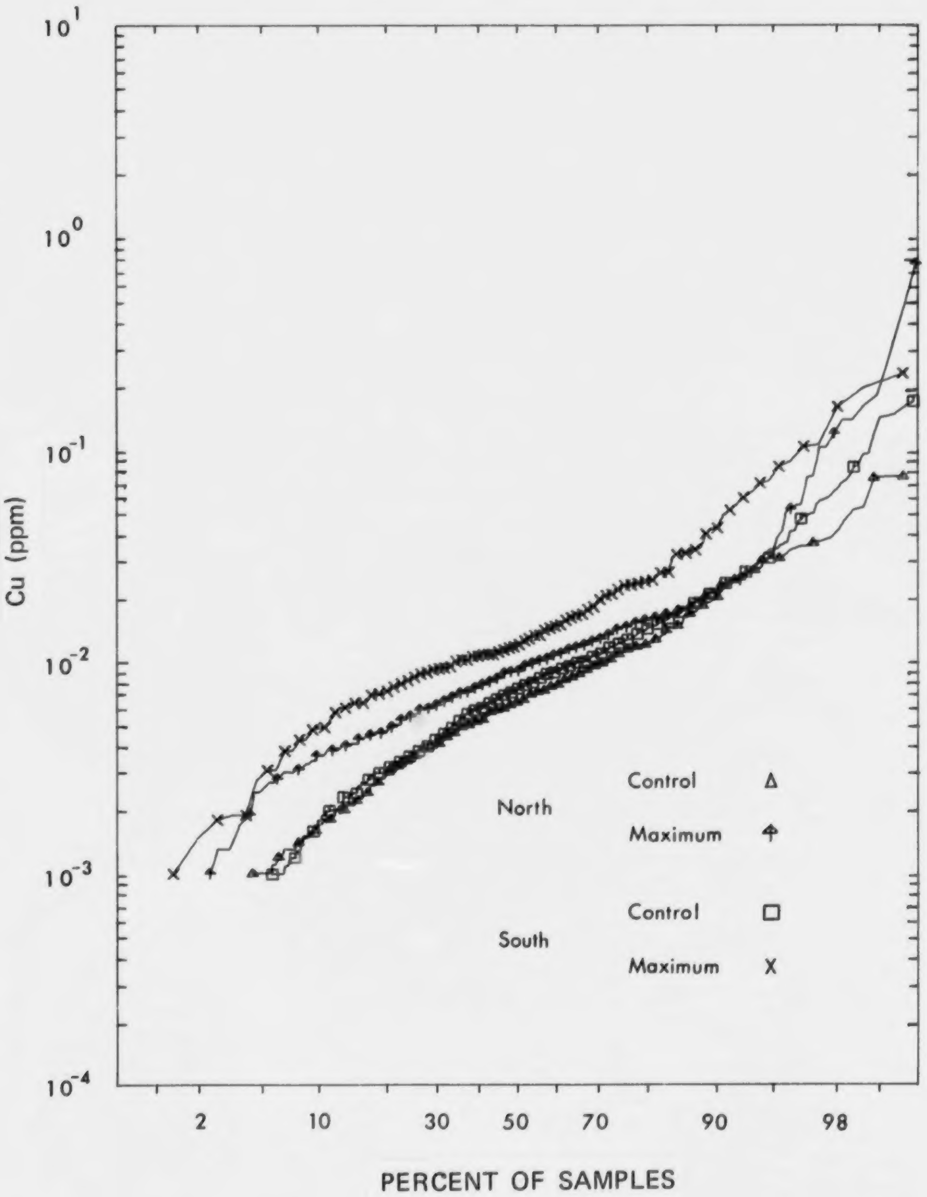

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Figure 79. Frequency distribution of Cu concentrations during the period 5/1/71 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Cu concentrations are percent of samples containing less than amounts shown on the vertical axis.

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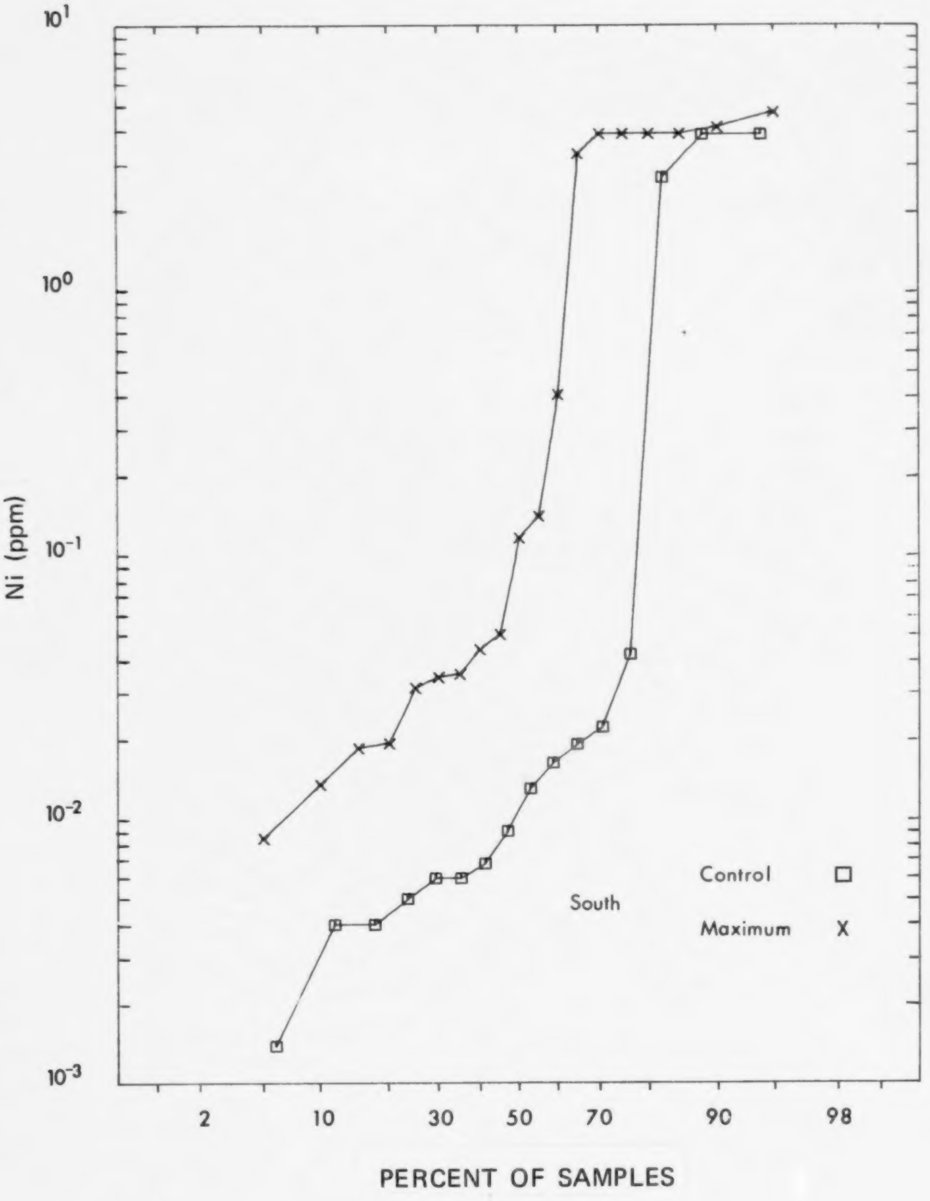

Figure 80. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Ni concentrations are percent of samples containing less than amounts shown on the vertical axis.

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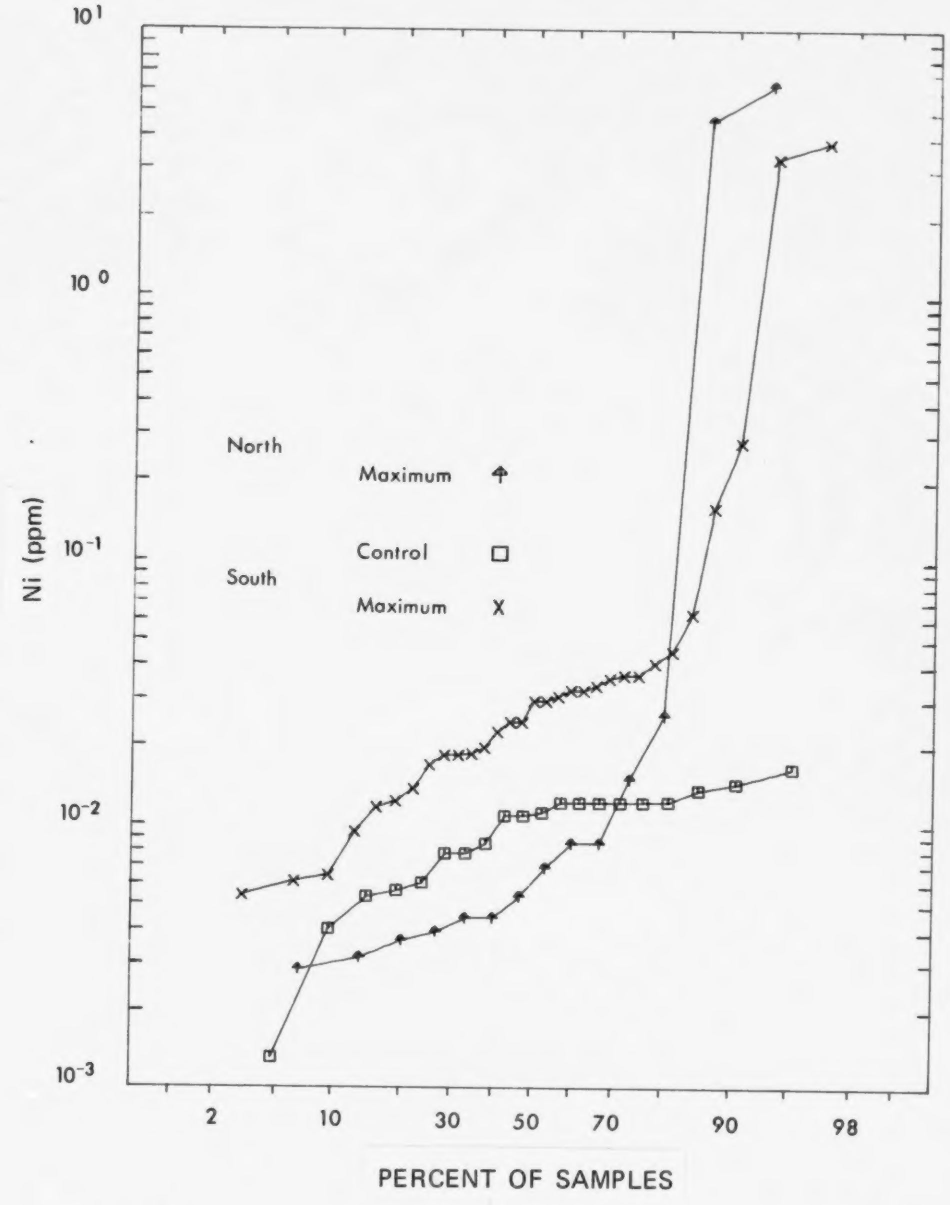

Figure 81. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of Ni concentrations are percent of samples containing less than amounts shown on the vertical axis.

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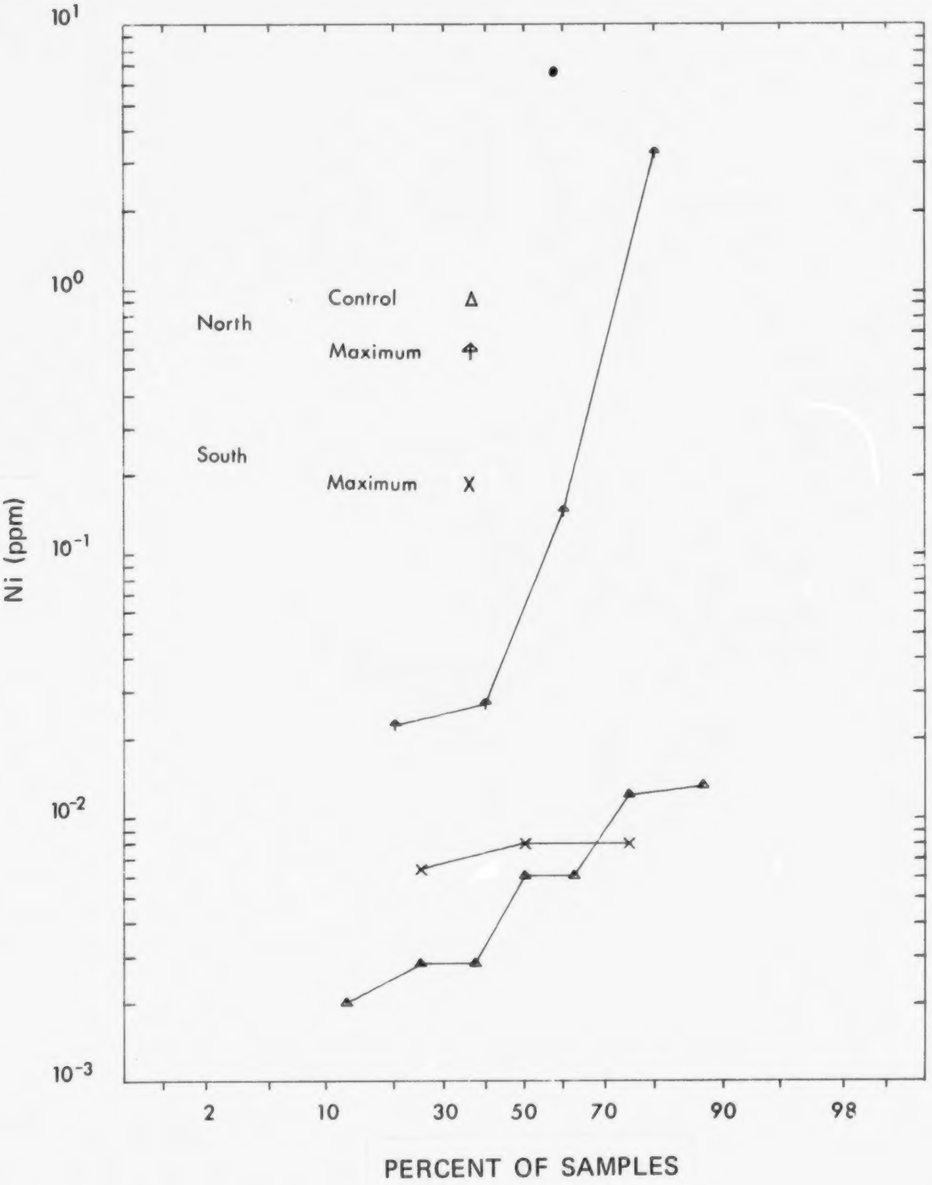

Figure 82. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Ni concentrations are percent of samples containing less than amounts shwon on the vertical axis.

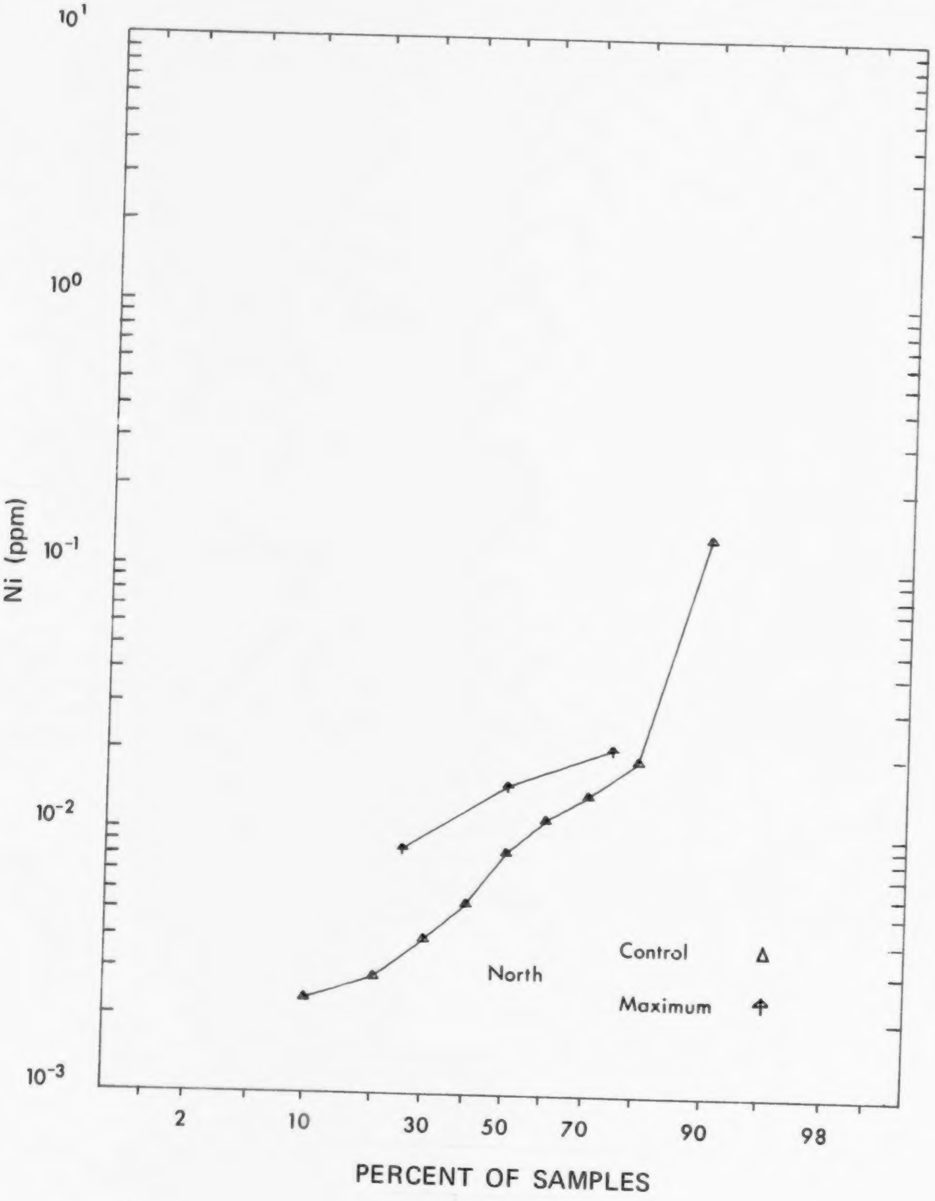

Figure 83. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of Ni concentrations are percent of samples containing less than amounts shown on the vertical axis.

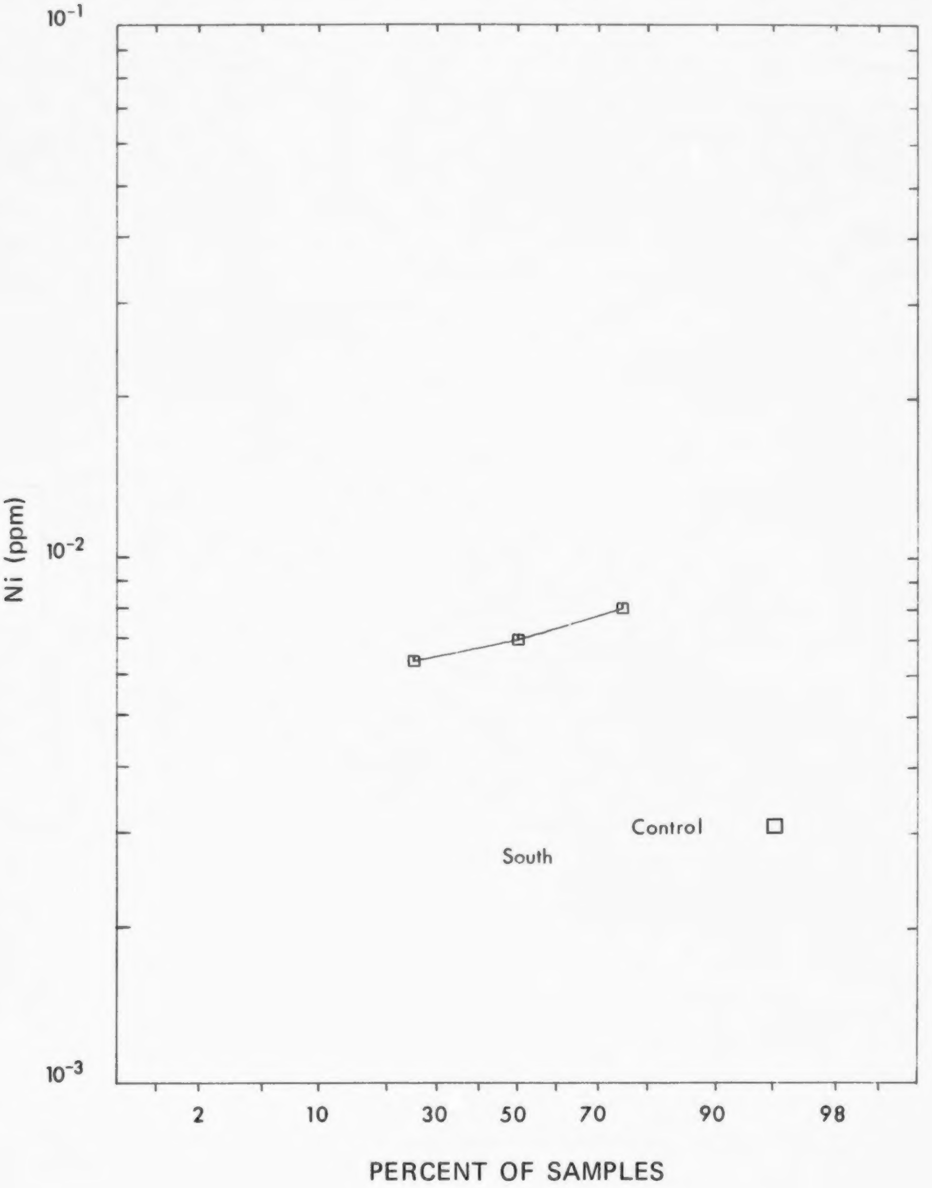

Figure 84. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in runoff water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Ni concentrations are percent of samples containing less than amounts shown on the vertical axis.

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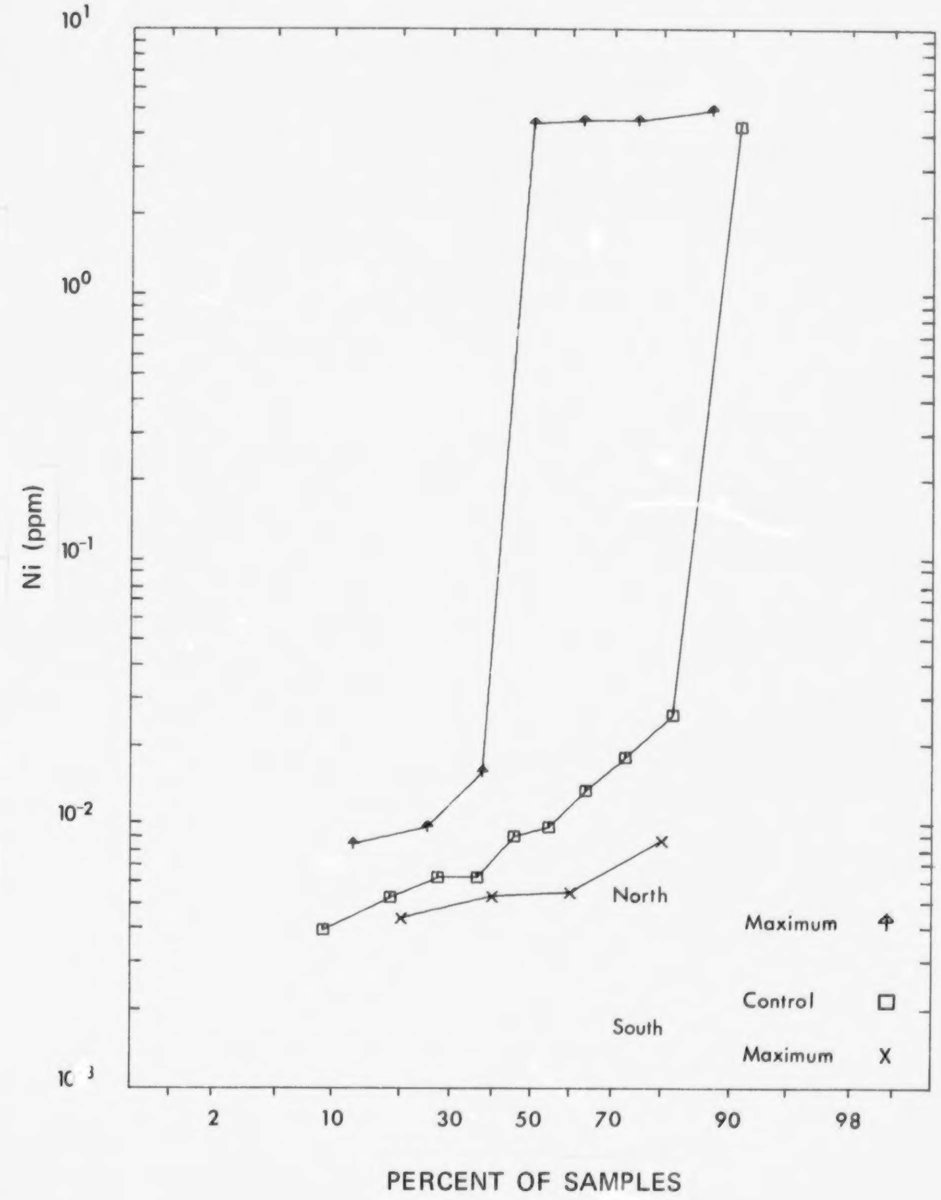

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Figure 85. Frequency distribution of Ni concentrations during the period 5/1/76 to 4/30/77 in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of Ni concentrations are percent of samples containing less than amounts shown on the vertical axis.

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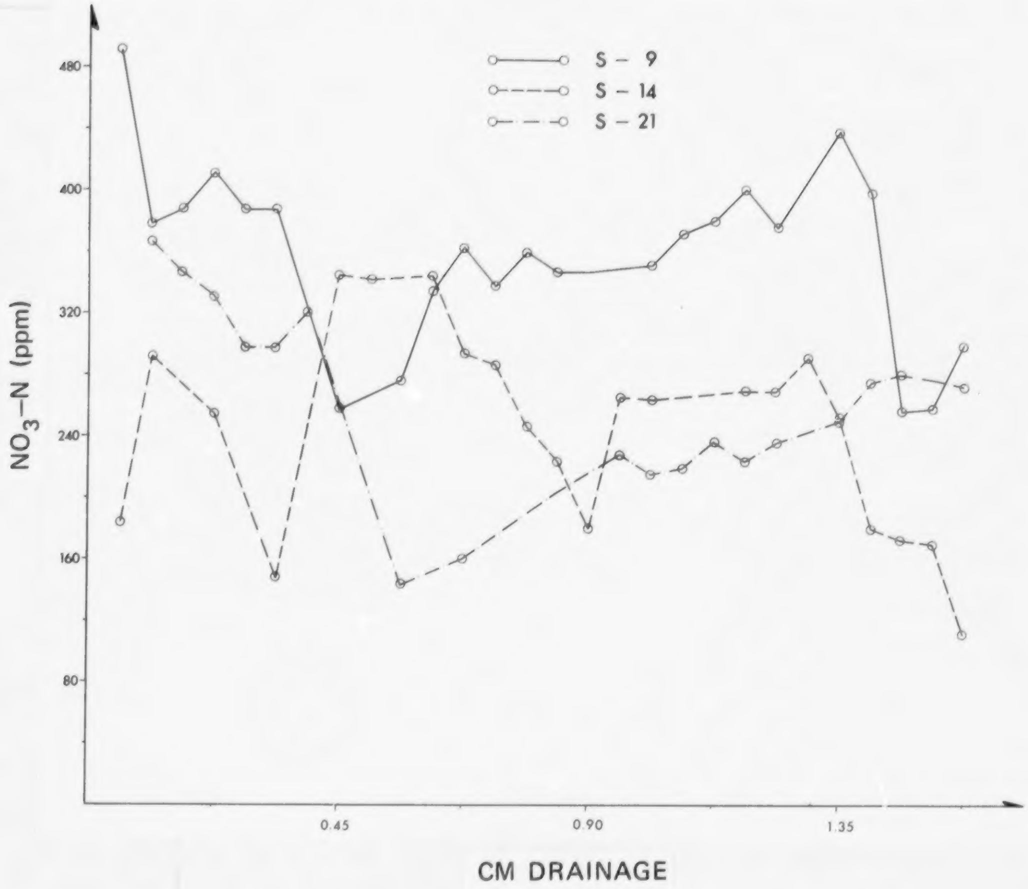

Figure 86. Fluctuating NO_3-N contents of drainage water with accumulative flows during a period of 41 days in 1972. The lysimeter plots S-9, S-14, and S-21 were replicated treatments of maximum sludge application rates on Blount silt loam.

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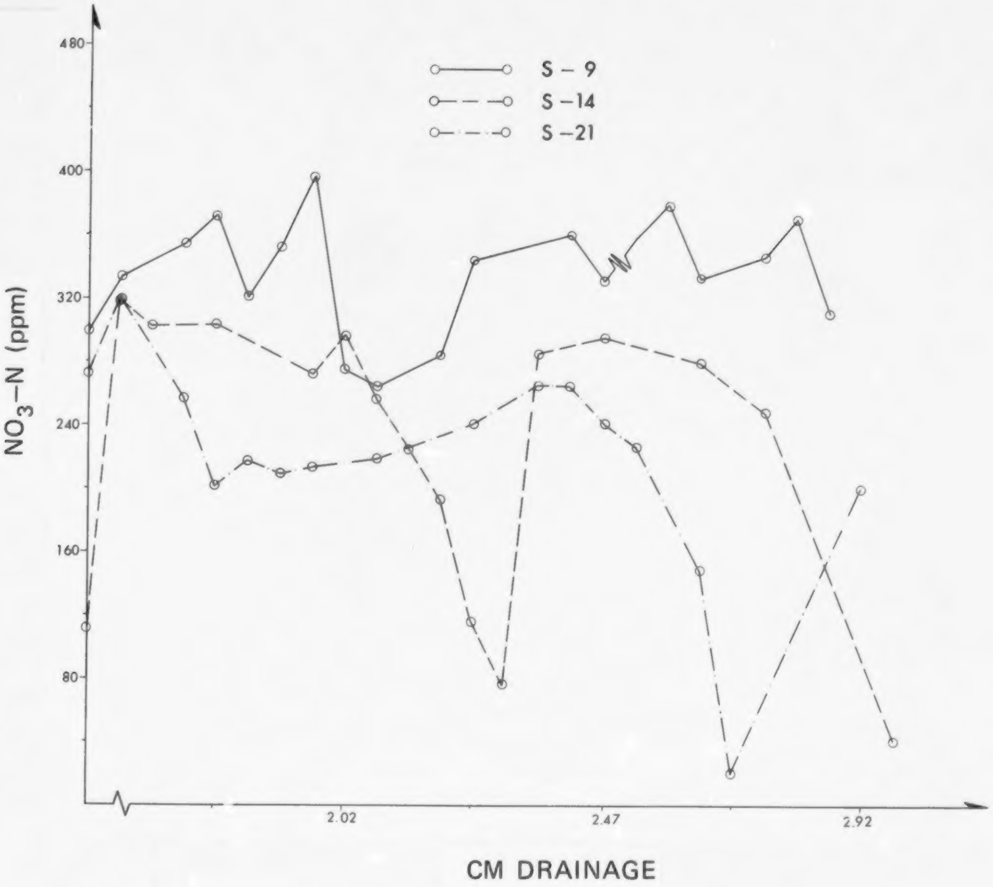

Figure 86. (continued) Fluctuating NO_3-N contents of drainage water with accumulative flows during a period of 41 days in 1972. The lysimeter plots S-9, S-14, and S-21 were replicated treatments of maximum sludge application rates on Blount silt loam.

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occurred during one drainage event in 1972. Using a sand tank, Mulqueen and Kirkham (1972) found an erratic variation in the salinity of drainage water until about one pore volume of water had drained, after which salinity declined exponentially. They attributed the variation to interaction between density and hydraulic gradients. Other factors no doubt contributed to the variations in NO_3-N concentrations in drainage water from field lysimeters. In the field lysimeter situation where sludge was being added periodically, some of the sludge-borne NH_4^+ was nitrified and organic-N was mineralized from previously incorporated supplies of sludge organic matter. Because of variable rates of nitrification and mineralization during different seasons, together with the effects of precipitation and evapotranspirational processes on the distribution of NO_3-N concentrations in the soil profile, periods of exponential decline in NO_3-N concentrations were not observed. Having observed the relatively large variations in NO_3-N levels in tile drainage water with time or total discharge as reported by others, Jury (1975) assumed that such fluctuation in concentration levels were the result of a phase delay due to travel time, which varied from point to point on the field. Materials leached from the soil profile over or near a tile drainage line can be assumed to reach the tile sooner than those leached from the soil half-way between tile lines. On this assumption, he developed a model relating the drain spacing, depth of tile, depth to impermeable zone, soil porosity, and mean discharge rate over the time of the study, for use in calculating the fraction of the applied nitrogen which might arrive at the tile line within a specified time. He pointed out the hazards of using effluent monitoring alone to assess the impact on ground water of a potential water contaminant applied on soil surfaces. Since not all of the contaminating substance will reach the soil drains at the same time, the relationship may be obscured between a leachable substance applied on the soil surface and concentrations of the same substance in drainage waters. In the field lysimeter, where a tile line drained a volume of soil only 1.5 m wide on each side, the effect of differences in transport travel time would have been small. Thus, variations in concentration of solubilized materials in drainage waters from a farm situation are likely to be greater than those observed in this study.

While plotting NO_3-N concentrations in drainage water as a function of cumulative drainage volume it was observed that the relationship between concentrations and drainage flow rates was also rather erratic. Sometimes NO_3-N concentrations increased with flow rates while decreases were associated with increased flow rates at other times. Also, it appeared that where greater total volumes of water percolated through a particular soil profile the peak maximum concentrations of NO_3-N in drainage water tended to be lower.

Between 30 to 40% of the total N applied on soils as a constituent of sludges was in the form of NH_4^+, while the remainder was organic-N. Considering amounts of total N applied on maximum-sludge-treated plots, NH_4-N concentrations in both runoff and drainage water were relatively low. On these plots annual applications of sludge-borne NH_4-N alone ranged from 3 to 14 times optimum amounts generally applied for corn production.

The reason for the low concentrations of NH_4-N in drainage water samples as found in our study is probably the same as that which has been put forward to explain low concentrations of this form of N in groundwater under feedlots

(Mielke, et al. 1970). Apparently, the major portion of the total N applied on the soil surface and unaccounted for in the runoff and drainage water was lost to the atmosphere. It seems likely that most of the loss was by direct NH_3 volatilization. Some evidence for rather large losses by this process is presented as Figures 87 and 88. These graphically depicted results were obtained by collecting sludge solids accumulated on the maximum-sludge-treated surface of Blount silt loam lysimeters in the south series of plots immediately after a sludge application on August 21 and November 16, 1973. Other samples were collected daily between these dates and the date of the next sludge application. All samples were analyzed for total N and NH_4-N concentrations. The dry weight N contents of solids, as plotted, are average values from 3 replicated lysimeter plots. It may be observed from the graphs that the decrease in total N concentrations is almost equivalent to the decreases in NH_4-N contents of sludge solids. Also, the decrease in NH_4-N contents were more rapid during August 21 to September 1 than in the November to December sampling period. This difference in rate reflected the high evapotranspirational potential that existed during the earlier sample collection period. Both total N and NH_4-N concentrations calculated on a dry weight of solids basis were considerably higher in sludge solids collected from the soil surface than in the original sludge applied. Most, but not all, of the increase in total N is due to increased NH_4-N contents. The difference between total N and NH_4-N contents is somewhat higher than is normally found in the applied digested sludge. This may indicate an increase of organic-N in sludge solids taken from the soil surface. One explanation is that organic and inorganic materials were segregated by more rapid sedimentation of inorganic solids during dewatering processes. Organic matter was concentrated in a surface film as liquid sludge slowly dried on the soil surface.

Although there is little doubt that losses of N from surface applied sludge by NH_3 volatilization are appreciable (perhaps 40 percent of total N), it is rather surprising that greater quantities of NH_4-N were not lost through drainage waters. Concentrations of NH_4-N in drainage waters were expected to be higher than those found in view of the amounts mineralized from sludge organics incorporated during spring plowing. In light of the findings reported by Dancer (1975), the fact that NH_4-N in drainage water from Plainfield loamy sand never exceeded a geometric mean concentration of 0.05 ppm is remarkable. Dancer (1975) applied various rates of $(NH_4)_2SO_4$ and $NaNO_3$ on sandy waste materials accumulated as a result of mining kaolin and observed the movement of NH_4^+ and NO_3^- forms of N with rainfall. Measurements during one summer showed that NO_3-N moved 4.1 cm/cm of rain as compared to 2.5 cm/cm for NH_4-N in sandy waste materials characterized by a cation exchange capacity of less than 2 meq/100 g. While some N may have been leached to lower depths in the NH_4^+ form in Plainfield loamy sand, most of it must have been oxidized before it reached the tile drains.

Fecal Coliforms in Drainage and Runoff

Organisms of the fecal coliform group are present in mammalian intestinal tracts in relatively high numbers, survive in water as long as most enteric pathogens, and can be easily identified using routine techniques. Thus, the fecal coliform group has long been used as an indicator of fecal contamination (Geldreich et al. 1965).

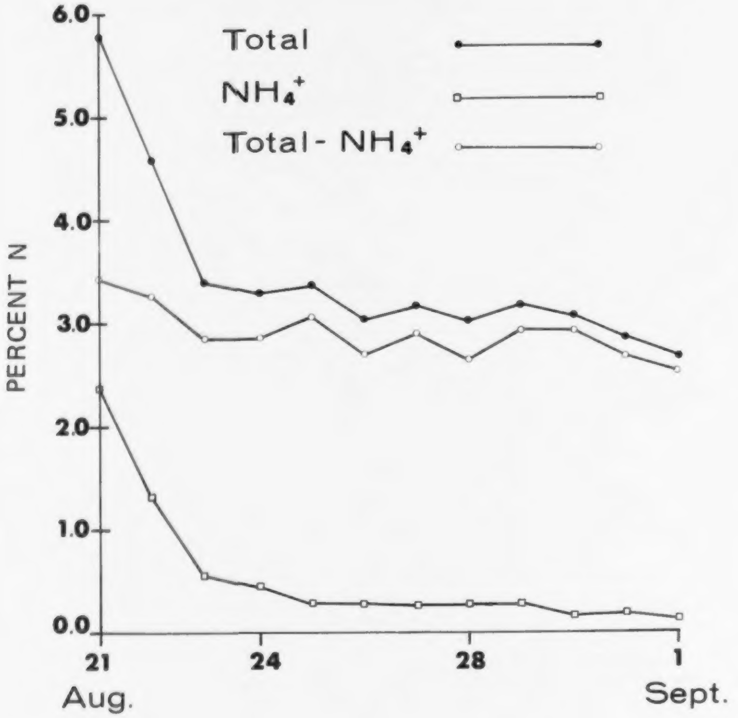

Figure 87. Changes in total N and NH_4-N concentrations in sludge solids accumulated on Blount silt loam soil surfaces following a 2.5 cm application of liquid digested sludge by furrow irrigation on 21 August 73.

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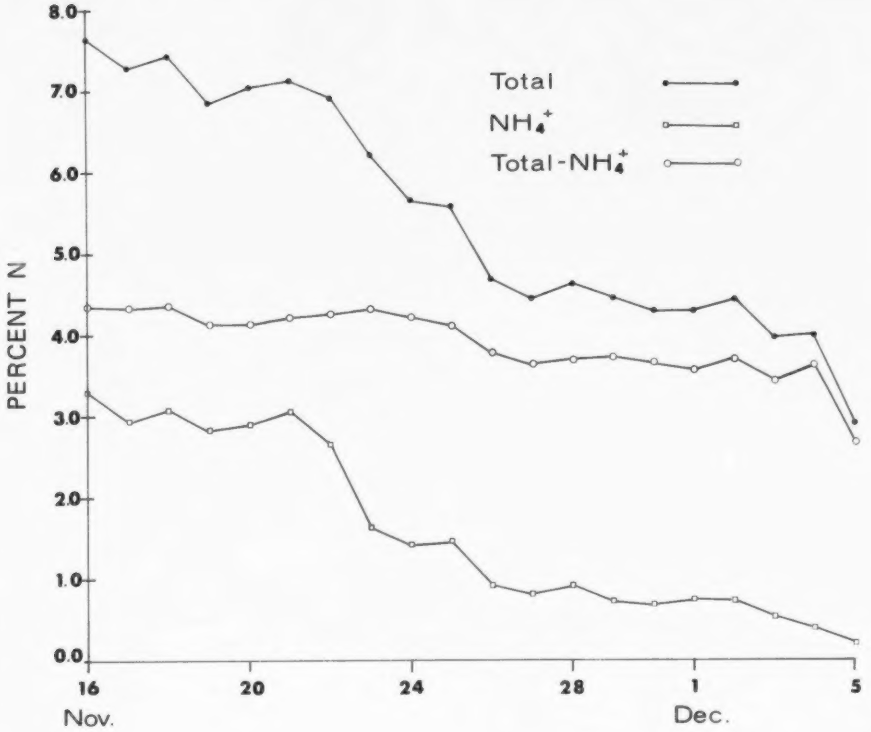

Figure 88. Changes in total N and NH_4-N concentrations in sludge solids accumulated on Blount silt loam soil surfaces following a 2.5 cm application of liquid digested sludge by furrow irrigation on 16 November 73.

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Fig. 88–148

Surface runoff and drainage water samples from the lysimeter plots were tested for fecal coliform by the membrane filter method within 36 hours of collection. Log-normal frequency distributions for concentrations of fecal coliform in runoff waters are presented as Figures 89 through 92. Concentrations in drainage waters from the three soil types are presented as Figures 93 through 98. Fecal coliform concentrations were apparently not log-normally distributed because of the relatively large variations that existed between seasons. Therefore, it appeared advantageous to group the fecal coliform data according to variations in soil temperatures recorded throughout the year. Daily soil temperatures, at the 10 cm depth, were averaged on a weekly basis for data that extended from February 1970 to May 1974. The data were then analyzed according to five Julian date periods of 15 to 91, 92 to 175, 176 to 245, 246 to 322, and 323 to 14 days during which average soil temperatures were less than 5°C, 5 to 20°C, greater than 20°C, 20 to 5°C, and less than 5°C, respectively. Within these five time periods, fecal coliform data for drainage water samples were separated according to concentrations ranging from 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500 and greater than 500 counts/100 ml.

Differences between fecal coliform levels of drainage water from the silt loam soils and Plainfield loamy sand plots are evident in all seasons (Figures 99-101). The Plainfield loamy sand plots consistently yielded a higher percentage of samples in the 0 to 1 count/100 ml range than either Blount or Elliott silt loam soils. This difference is particularly evident from July to early January when counts in drainage water from loamy sands remained low while those from the silt loam soils increased in an apparent response to sludge treatment. Fecal coliform counts in drainage waters from Elliott and Blount silt loam soils were not different. These results indicate a much higher survival rate for fecal coliforms in silt loam as compared to loamy sand and may be due to differences in soil moisture contents.

In general, comparison of coliform counts between untreated and maximum-sludge-treated plots (Figures 102 and 103) show only a slight increase in counts due to treatment. Data for the months of July and August (176 to 245) showed the greatest difference. However, very few drainage water samples were received during this period so the number of observations per class was small. Since the period coincided with the heaviest sludge application, these results might have been predicted.

The most interesting results were those which indicate seasonal differences. The set of histograms exhibited as Figure 104 for all soils and treatments combined showed the response that was apparently manifested in all the plots. Counts were highest beginning in early summer and corresponded to the time of actual sludge application. By December the percentage of higher counts had begun to decline and continued to do so until late spring just prior to the resumption of sludge application. Each soil type has been shown to exhibit this same response. The question obviously arises as to why the untreated plots should exhibit this same seasonal response. Aside from the possibility of contamination from treated plots by wind erosion it has been shown that soil thought to be uncontaminated often contain fecal coliforms introduced by wildlife (Geldreich, et al., 1965). Maximum survival of fecal

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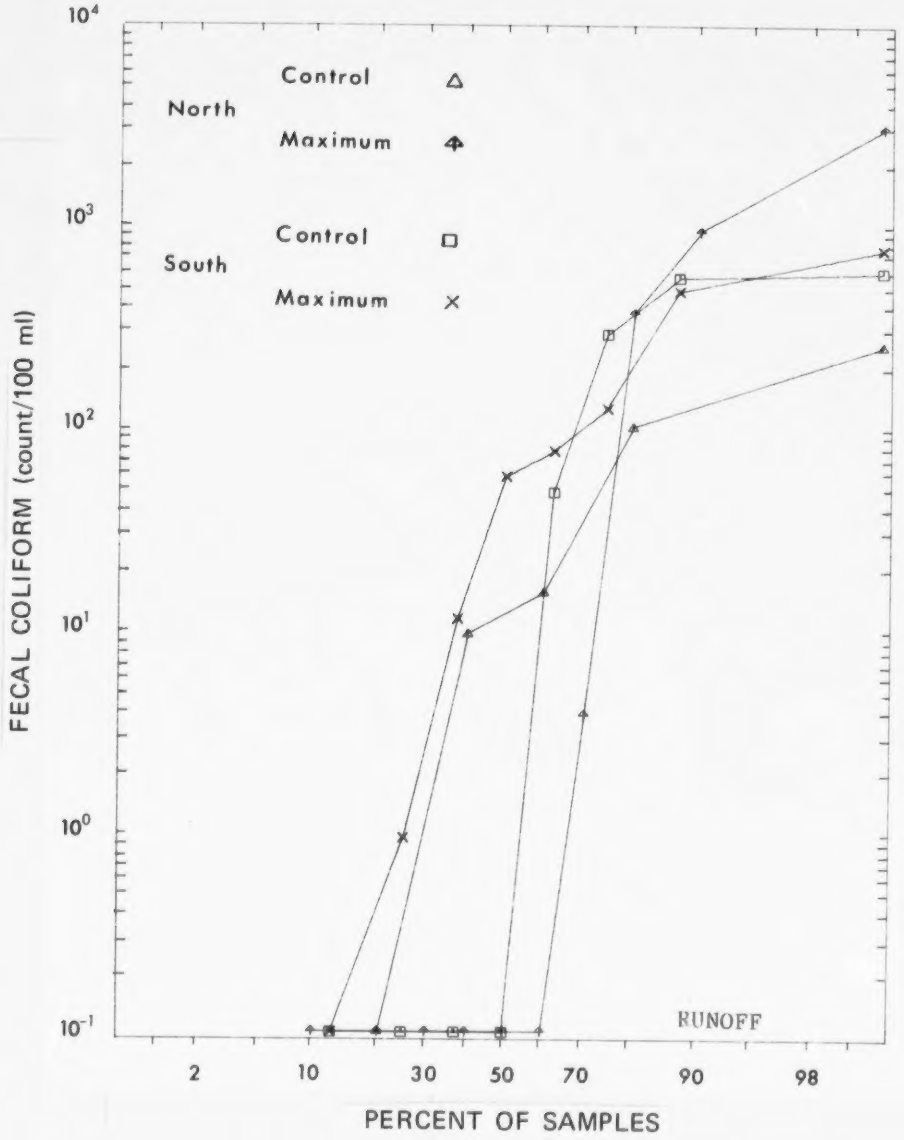

Figure 89. Frequency distribution of fecal coliform concentrations during the period May 1, 1972, to April 30, 1973, in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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Fig 89-151

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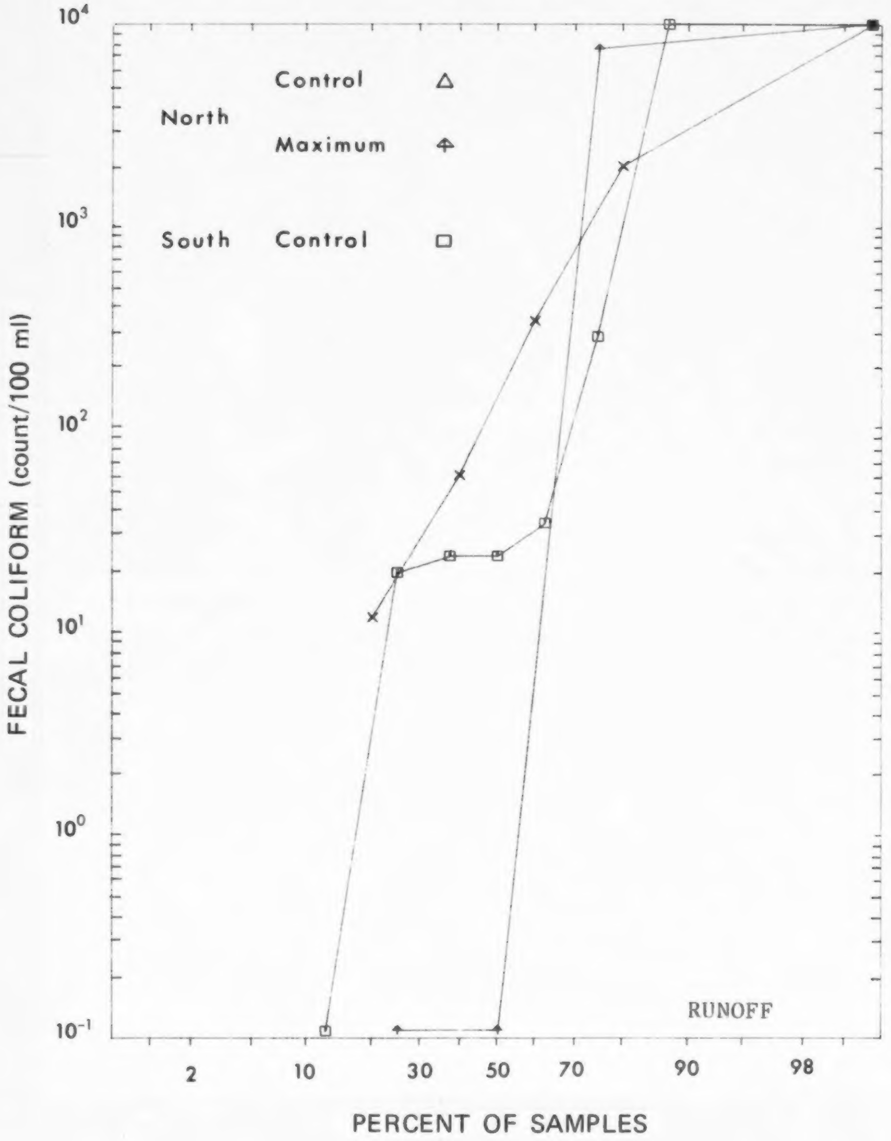

Figure 90. Frequency distribution of fecal coliform concentrations during the period May 1, 1973, to April 30, 1974, in runoff water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

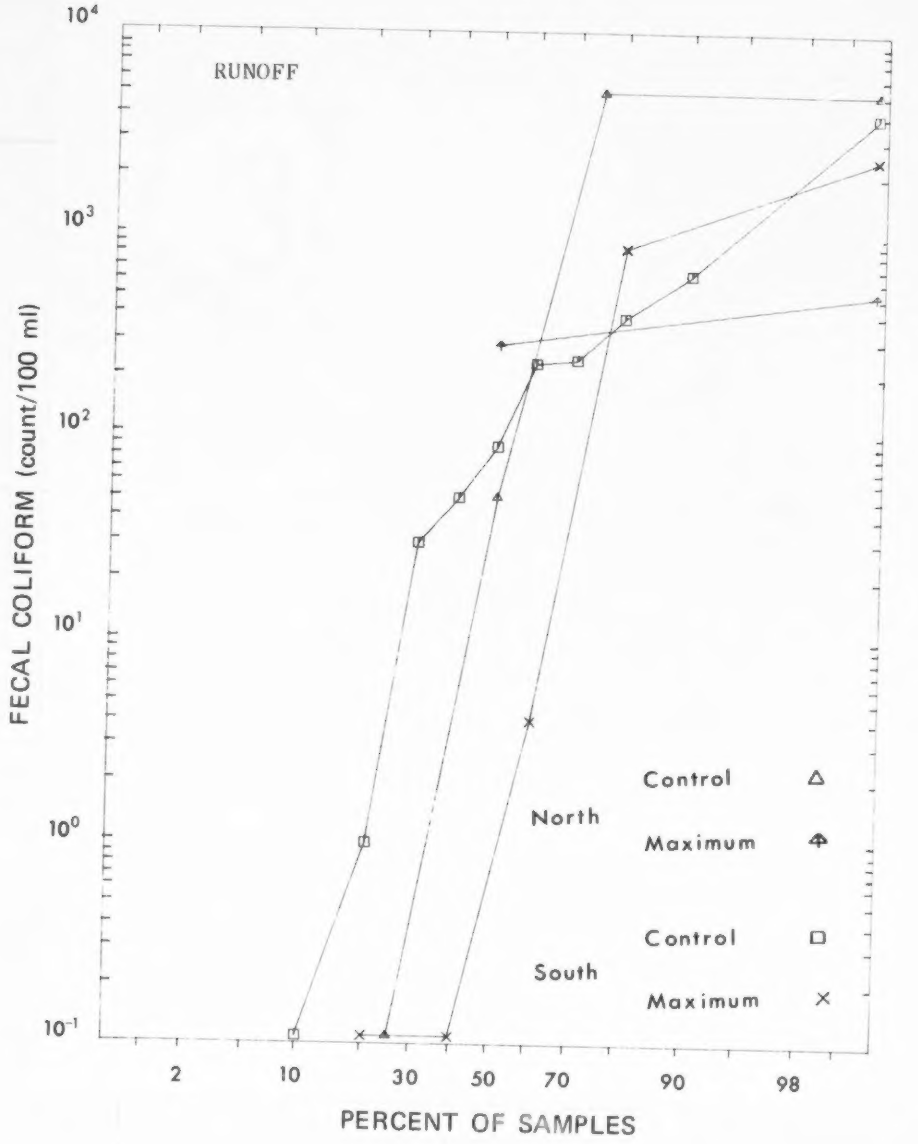

Figure 91. Frequency distribution of fecal coliform concentrations during the period May 1, 1972, to April 30, 1973, in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

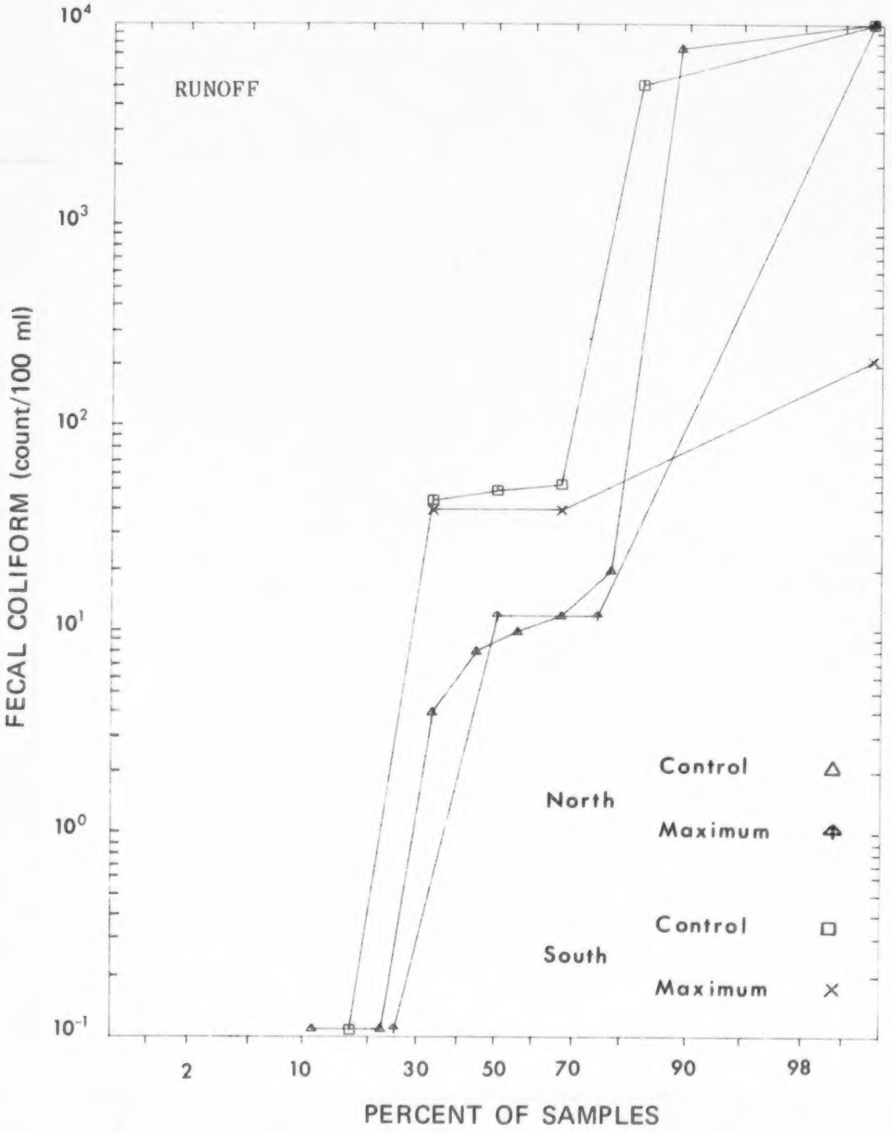

Figure 92. Frequency distribution of fecal coliform concentrations during the period May 1, 1973, to April 30, 1974, in runoff water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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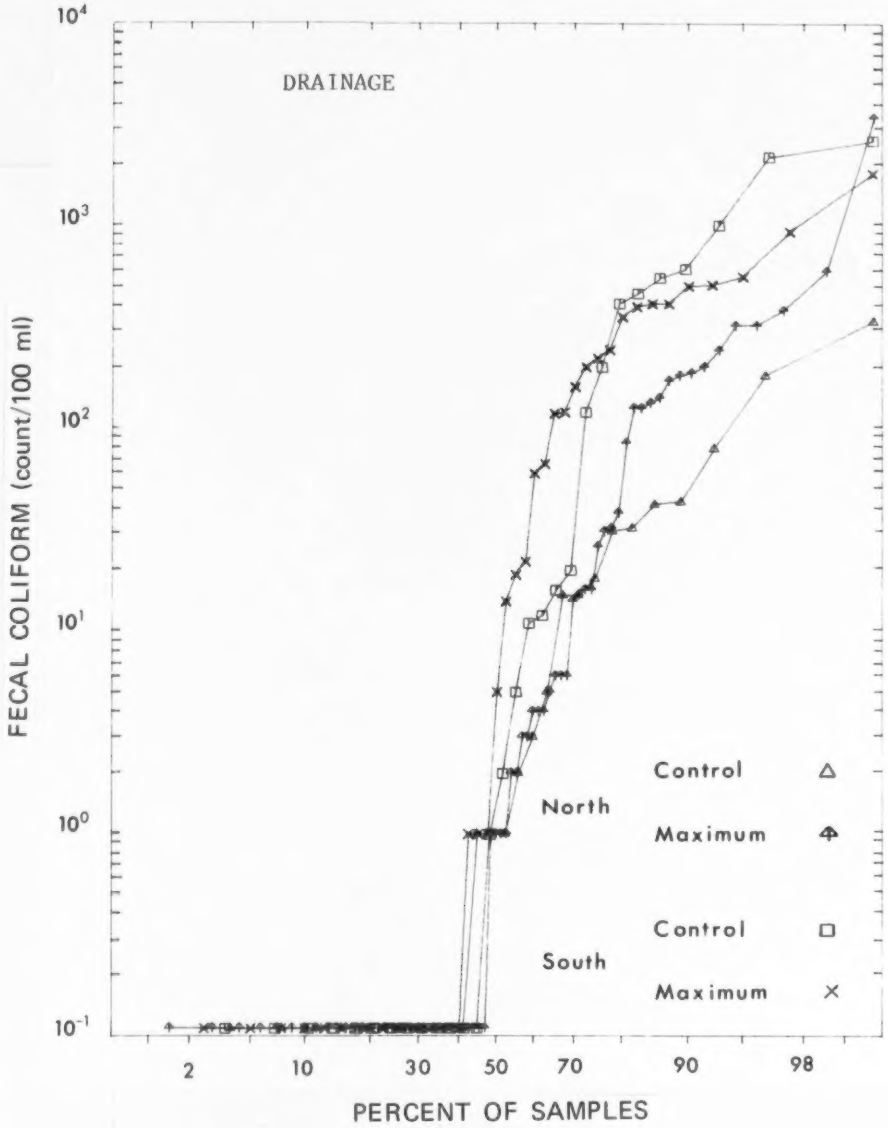

Figure 93. Frequency distribution of fecal coliform concentrations during the period May 1, 1972, to April 30, 1973, in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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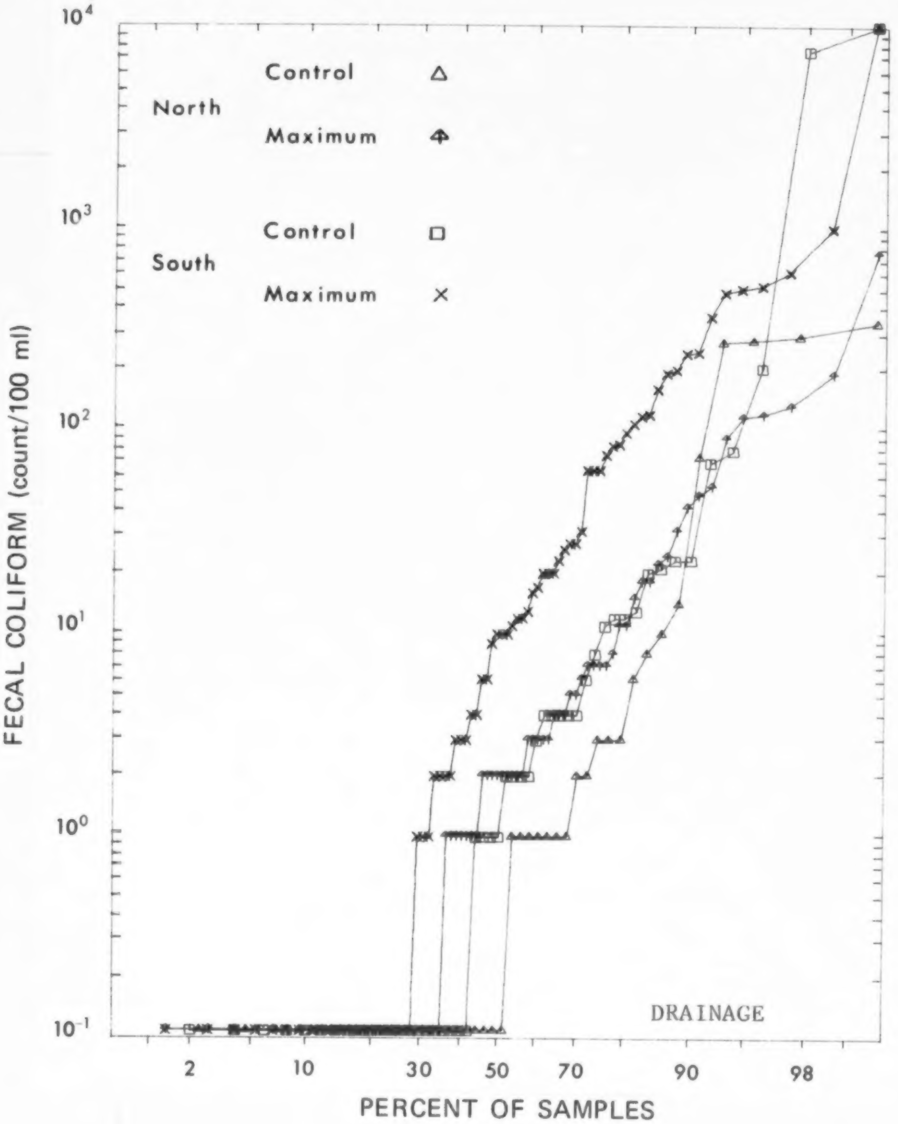

Figure 94. Frequency distribution of fecal coliform concentrations during the period May 1, 1973, to April 30, 1974, in drainage water samples collected from field lysimeter plots containing Blount silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

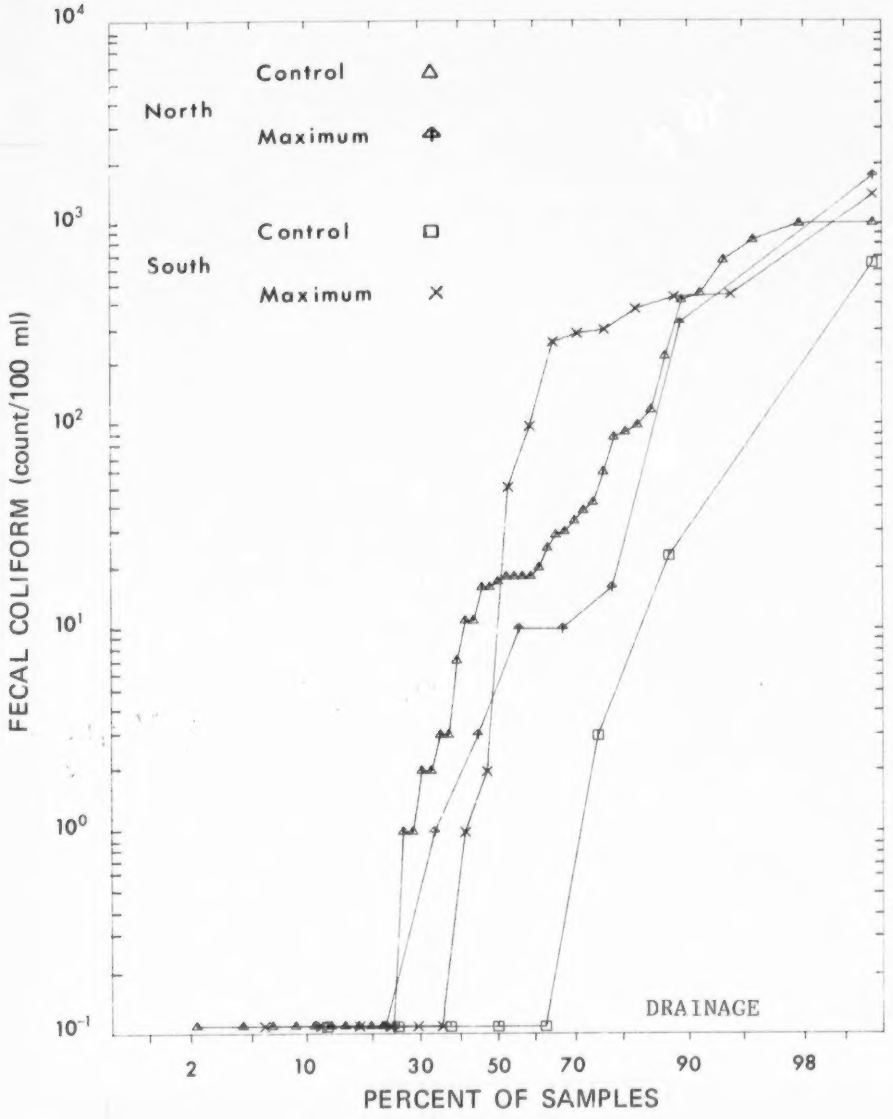

Figure 95. Frequency distribution of fecal coliform concentrations during the period May 1, 1972, to April 30, 1973, in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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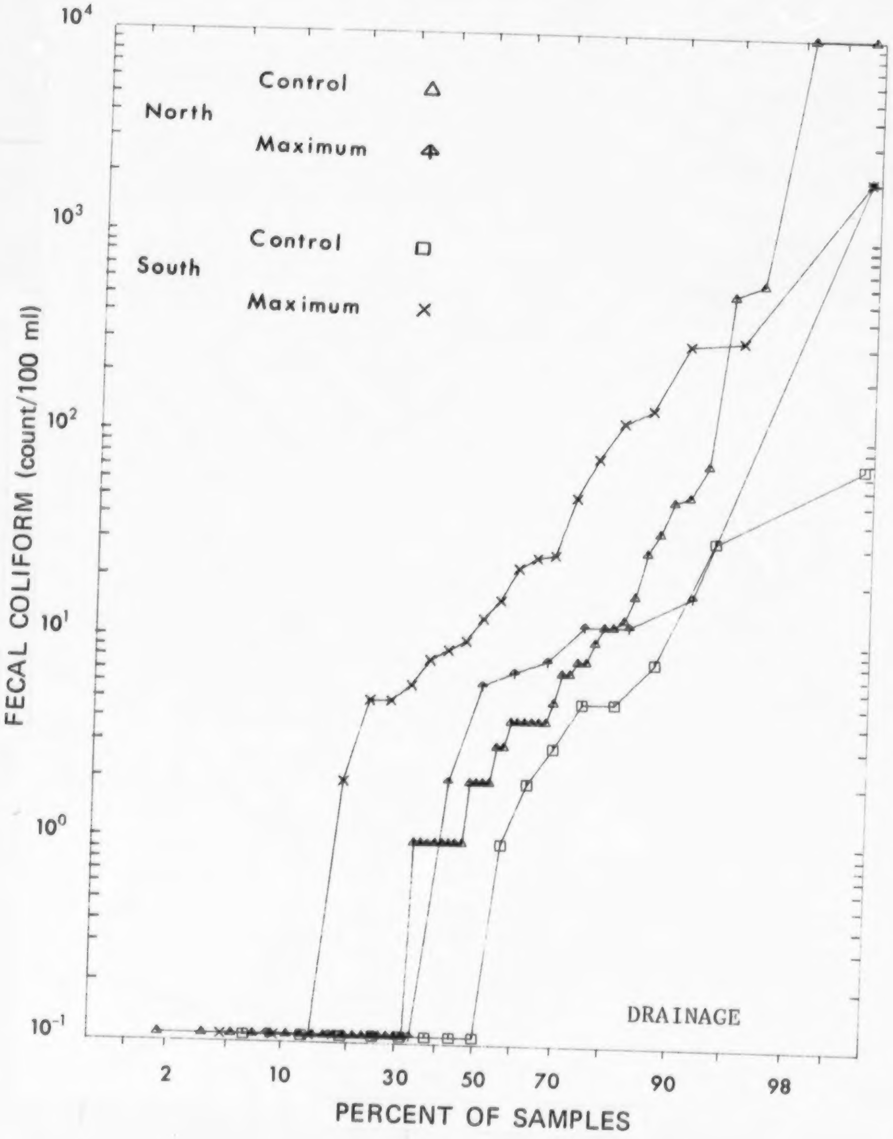

Figure 96. Frequency distribution of fecal coliform concentrations during the period May 1, 1973, to April 30, 1974, in drainage water samples collected from field lysimeter plots containing Elliott silt loam soil. Distribution of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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Fig 96 - 156

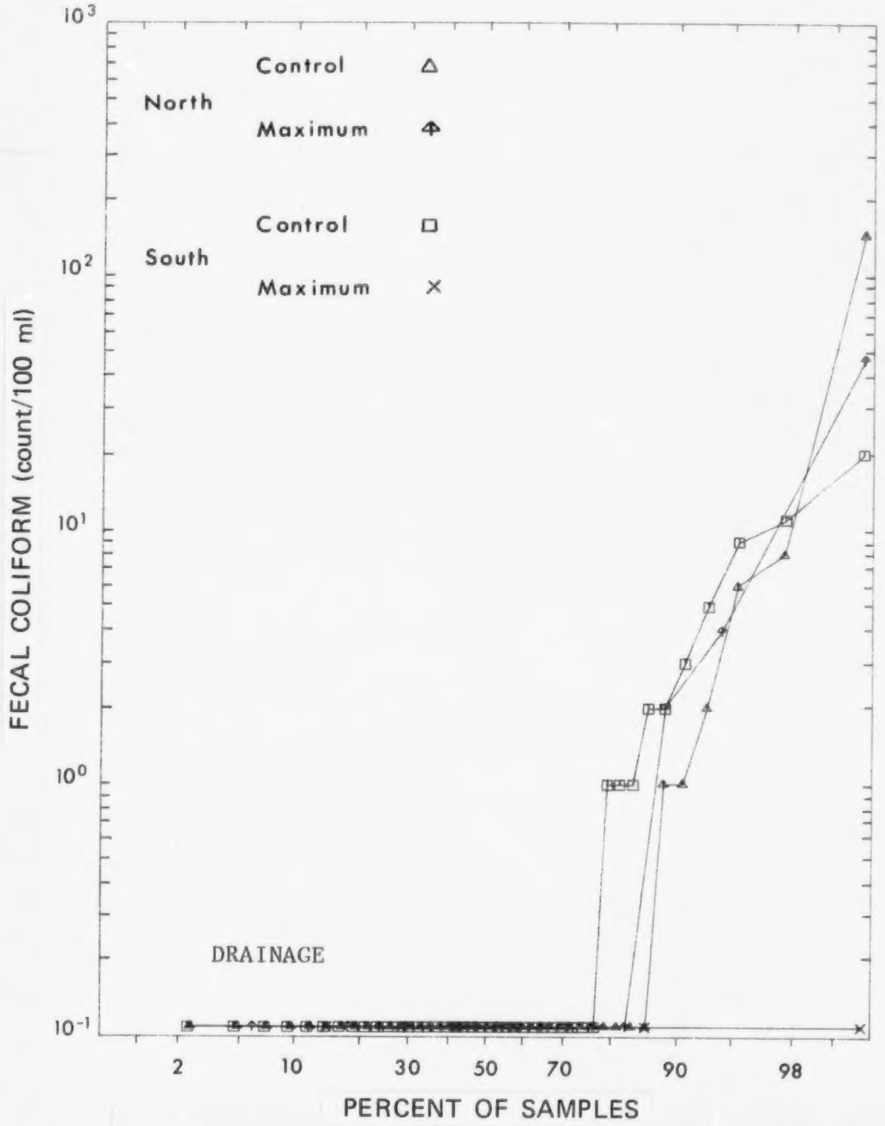

Figure 97. Frequency distribution of fecal coliform concentrations during the period May 1, 1972, to April 30, 1973, in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of fecal coliform concentrations are percent of samples containing less than amounts shown on the vertical axis.

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F 97 - 159

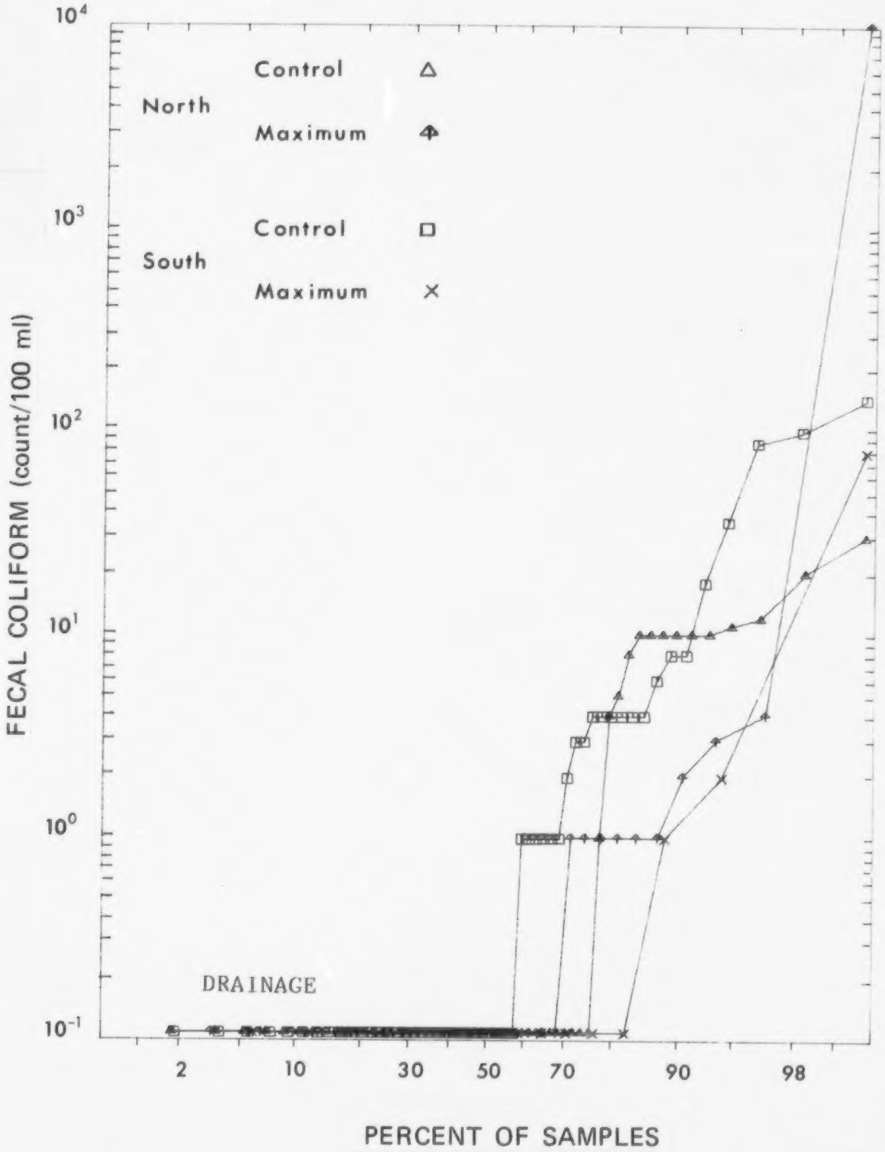

Figure 98. Frequency distribution of fecal coliform concentrations during the period May 1, 1973, to April 30, 1974, in drainage water samples collected from field lysimeter plots containing Plainfield loamy sand. Distributions of fecal coliform concentrations are percent of samples containing less than amounts on the vertical axis.

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Fig 98 - 160

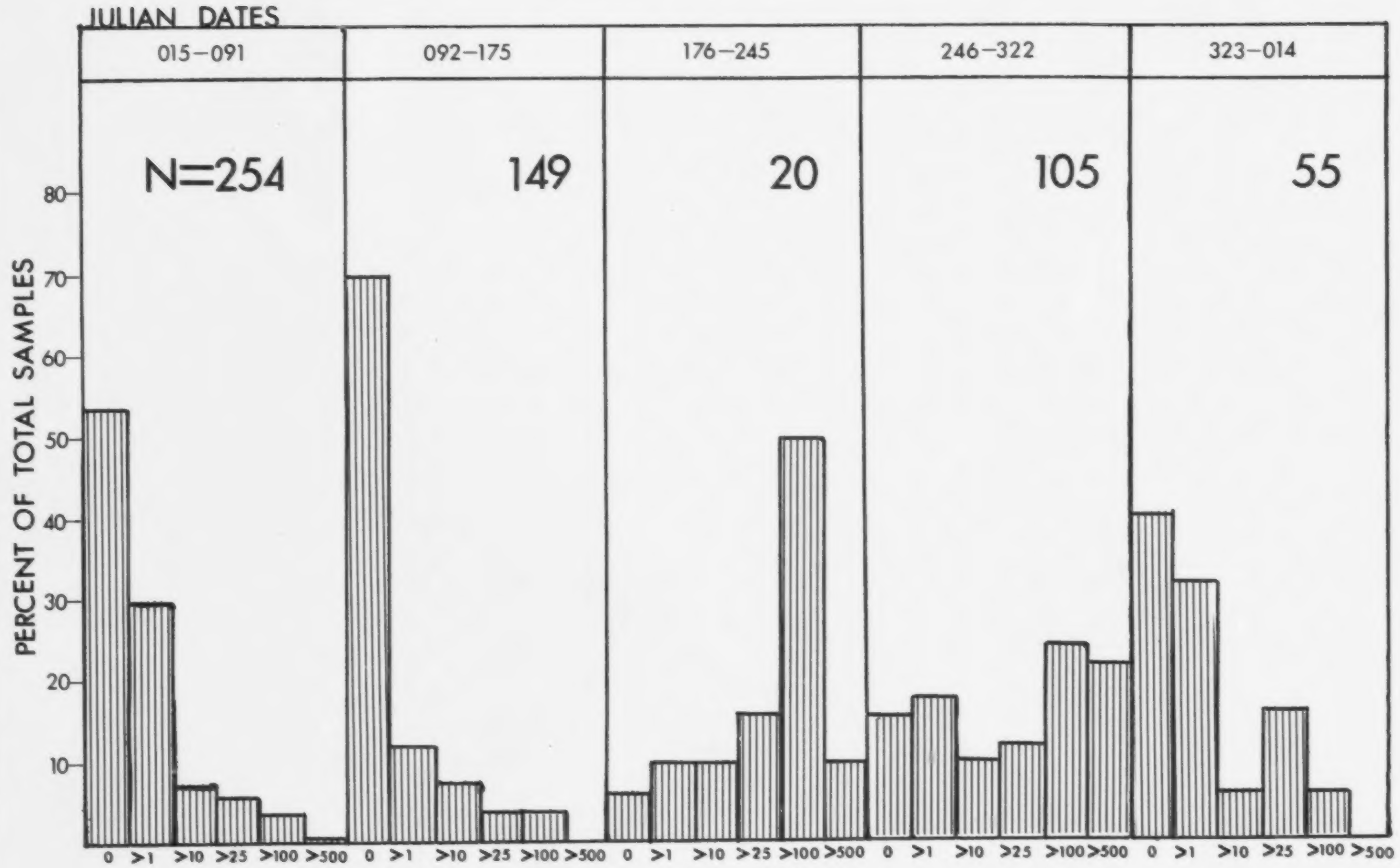

Figure 99. Percent of drainage water samples from Blount silt loam lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from all treatments were combined.

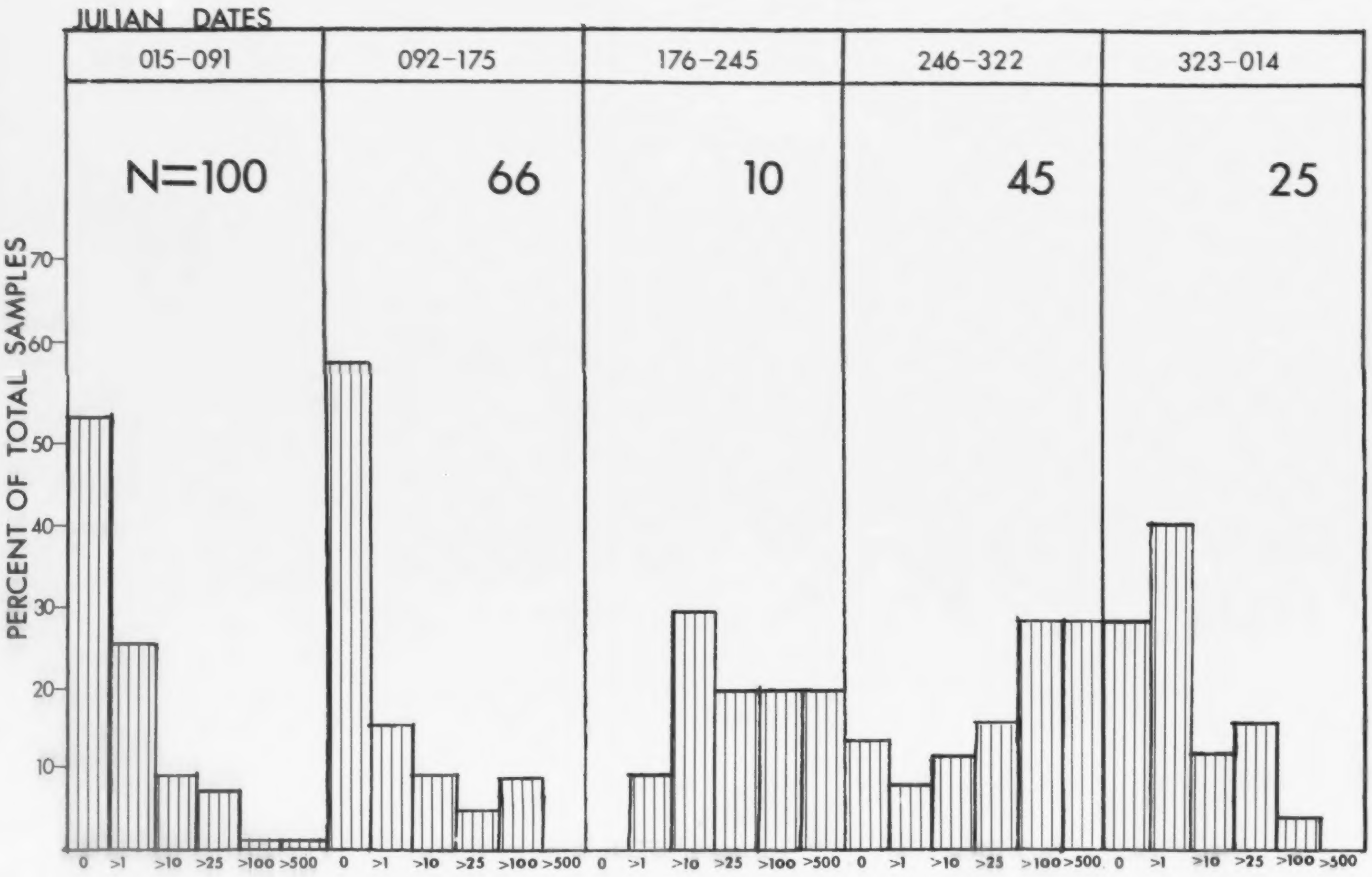

Figure 100. Percent of drainage water samples from Elliott silt loam lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from all treatments were combined.

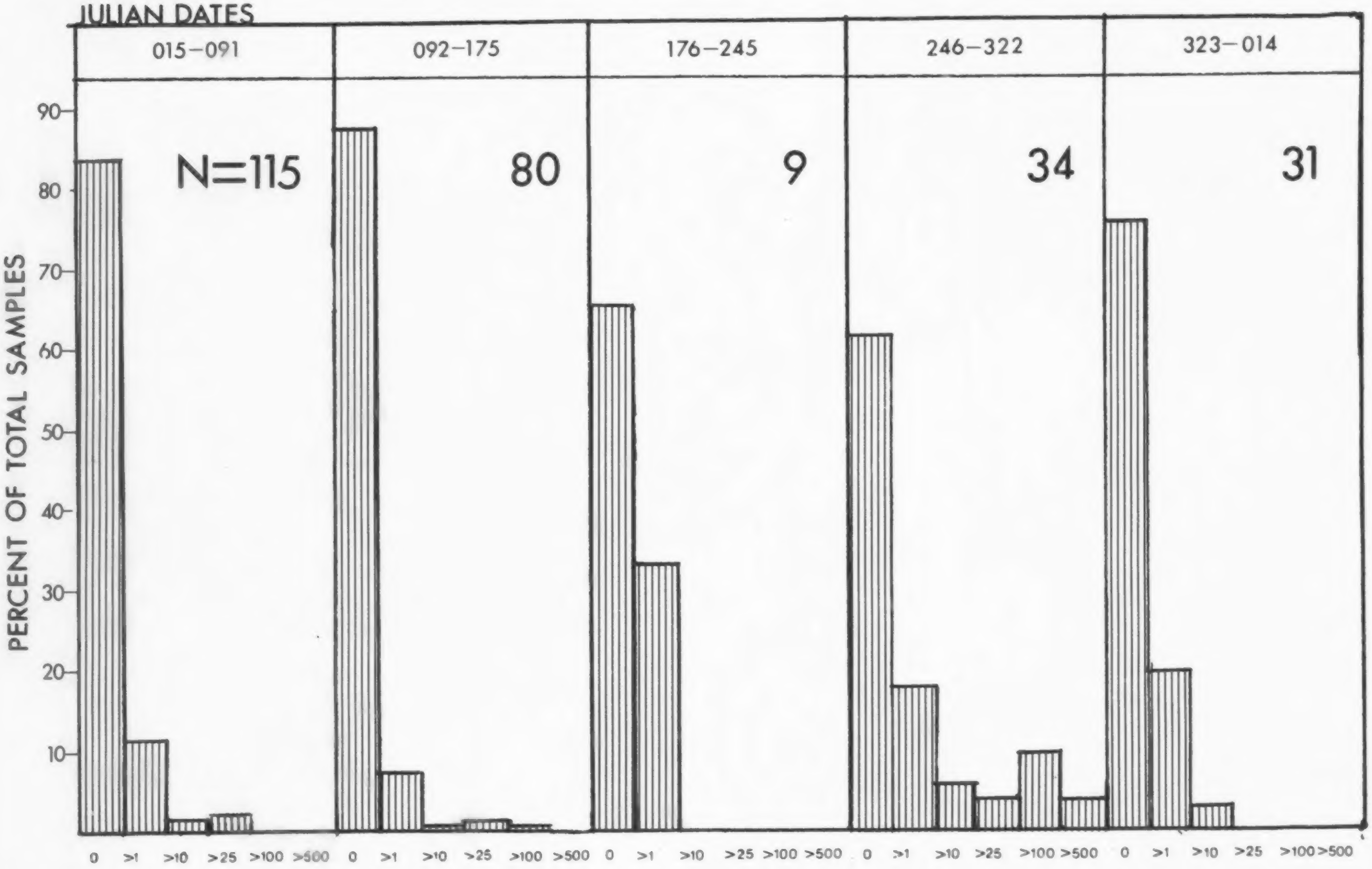

Figure 101. Percent of drainage water samples from Plainfield loamy sand lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from all treatments were combined.

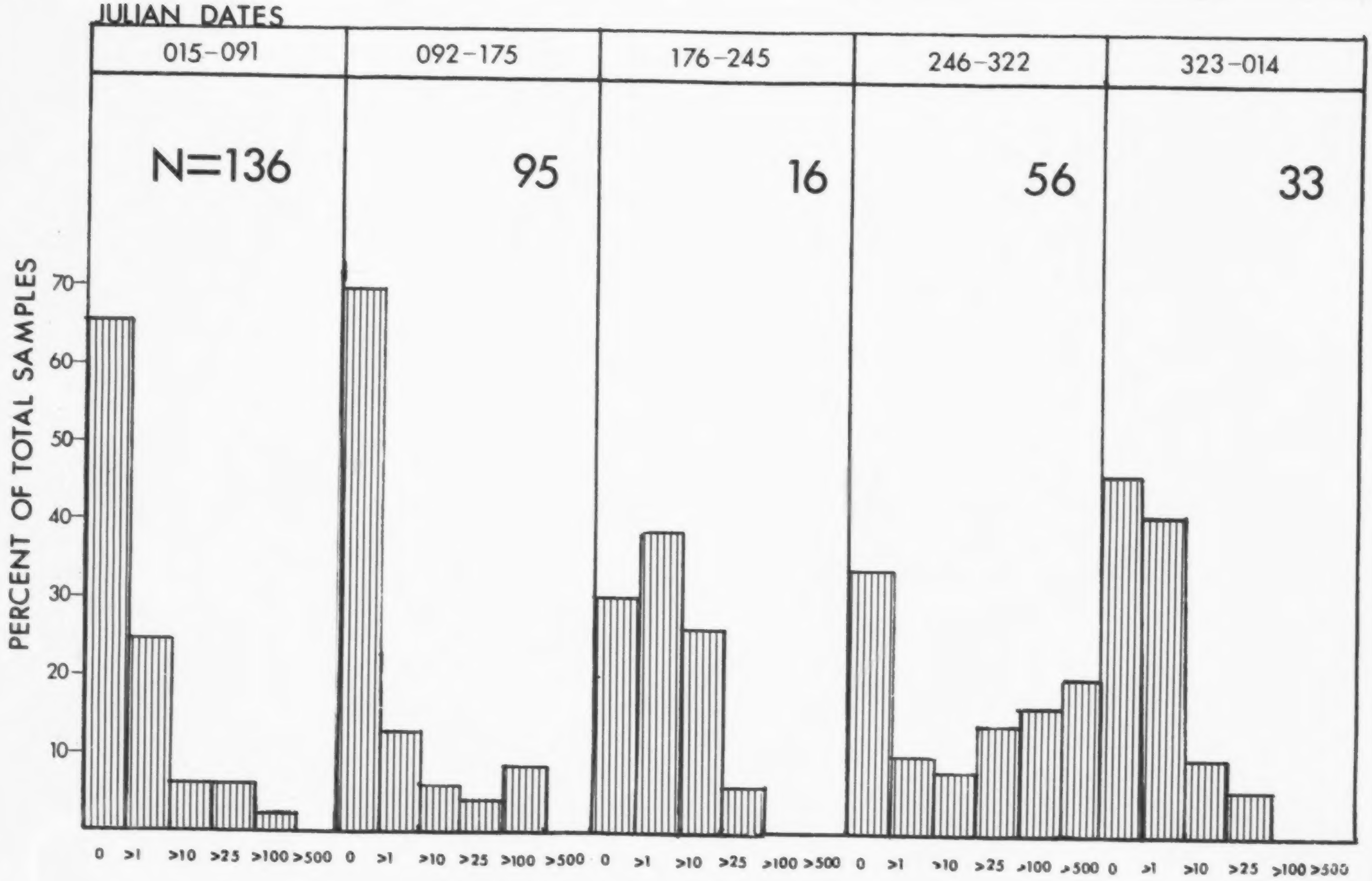

Figure 102. Percent of drainage water samples from control lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from three soil types were combined.

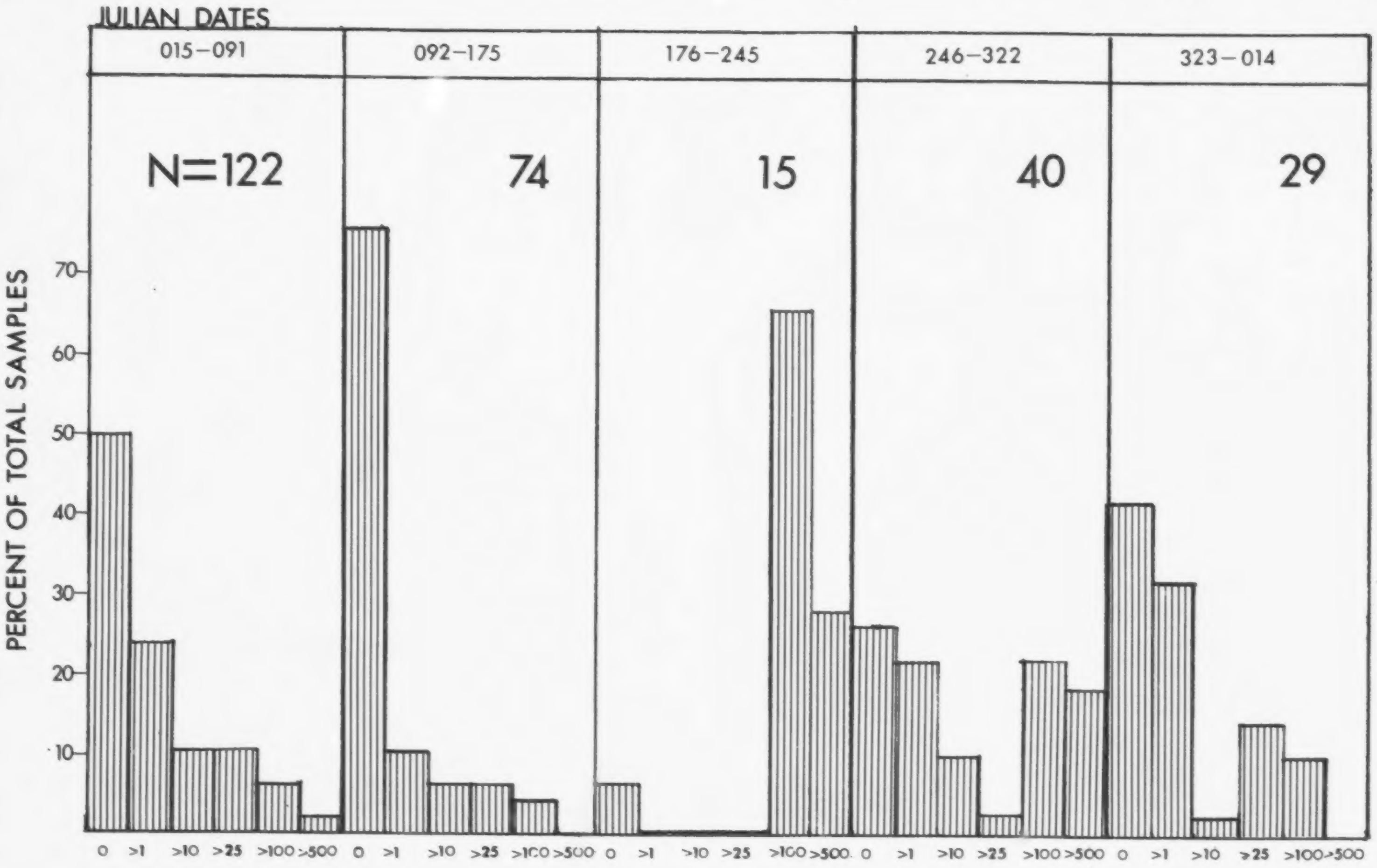

Figure 103. Percent of drainage water samples from maximum sludge-treated lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from three soil types were combined.

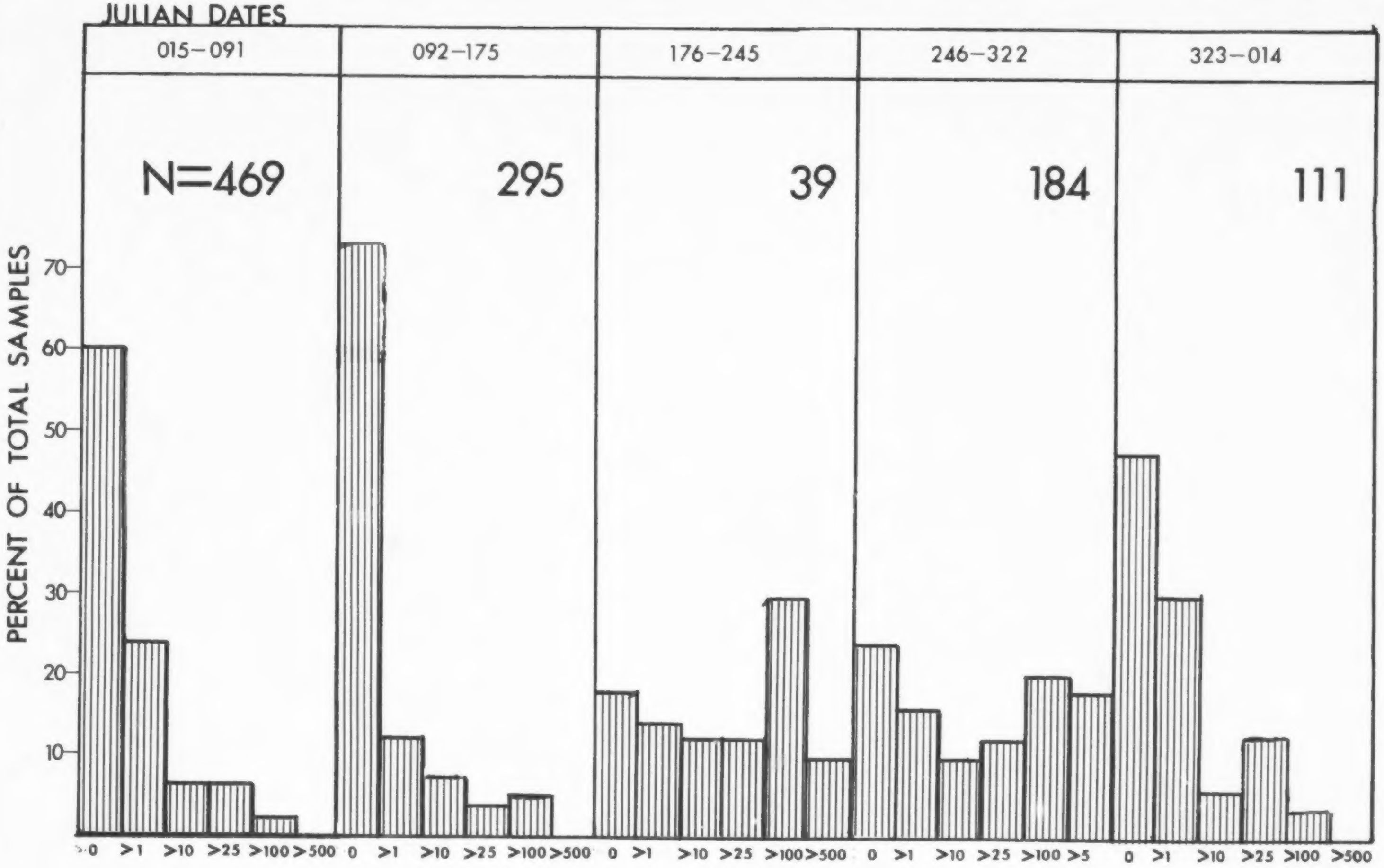

Figure 104. Percent of drainage water samples from lysimeter plots that contained 0 to 1, 2 to 10, 11 to 25, 26 to 100, 101 to 500, and greater than 500 fecal coliform organisms. Data from all soil types and treatments were combined.

coliforms in soils occurs during the summer in shaded locations and during the fall in exposed sites (Van Donsel, et al., 1967). It is apparent that agricultural cropping and sludge application practices produce conditions which would maximize the abundance of fecal coliforms in the soil at particular times.

Changes in Chemical Properties of Soils

Maximum-sludge-treatments caused increased organic-C concentrations in the plow-layer (0 to 15 cm depth) of all soils in both the north and south series (Table 7). Organic-C concentrations were increased in the soil surface by 1/2-maximum-sludge-treatments during 4 and 5 of the 7 years of annual applications on Blount silt loam plots in the north and south series, respectively. Concentrations of organic-C in the surface of Blount silt loam soil were increased by 1/4-maximum-sludge-treatments during only the years of 1974 and 1976 in plots located in the south series. Annual sludge applications were terminated on all north series plots except maximum-treated Elliott silt loam and Plainfield loamy sand plots after the 1973 growing season. Soil organic-C concentrations in Blount maximum-treated plots (north series) were not significantly different in 1977 than in 1972. They were significantly less in 1977 as compared to concentrations in 1974. Apparently, all but a small fraction of the total organic-C added as a constituent of sludge was lost very soon after incorporation, but after the first year the remainder was rather resistant to further losses. With continuous sludge applications the small resistant fractions each year caused rather permanent increases as indicated by higher organic-C concentrations in sludge-treated Blount silt loam soils (south series) in 1977 than in 1972. Annual tillage practices were the same in all years beginning in 1972. Similar sludge loading rates caused change in organic-C concentrations in the surface of Plainfield loamy sand that were similar to those in the finer textured soils. Contrary to expectations, the increase in concentrations of organic-C were greater in Plainfield loamy sand test soils, relative to levels in control soils, than in silt loam soils treated with similar sludge loading rates. These results were especially surprising in view of the fact that amounts of stover produced and returned to the soil surface were considerably less on Plainfield loamy sand than on silt loam plots (Table 9) which will be discussed in more detail later. There was no evidence that sludge applications had changed organic-C concentrations in subsoils of any soil type.

Regardless of location, Blount silt loam treated with maximum- or one-half-maximum sludge loading rates had higher total N concentrations in soil surfaces than control plots, during 6 of the 7 years. This was true even though sludge applications had been terminated after 1973 on plots in the north series. Sludge applications did not affect total N concentrations in soil depths below 15 cm. Like organic-C concentrations, total N concentration tended to remain fairly constant in soils after sludge treatments were terminated in 1973 on Blount silt loam and treatments less than maximum on Elliott silt loam and Plainfield loamy sand in the north series. Where annual sludge applications were continued on all plots in the south series and

(continued on Page 198)

TYPING GUIDE SHEET

TABLE 7. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS AND SOIL pH IN BLOUNT SILT LOAM, ELLIOTT SILT LOAM AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS LOCATED IN A NORTH AND SOUTH SERIES.[a/]

Parameter	Depth cm	Year	Soil type											
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			----------------					%							----------------
Organic-C															
	North Series														
	0-15	71	0.85	1.06	1.38	1.62	0.52**	1.64	1.64	1.97	2.23	0.39	0.36	0.58	0.90
		72	0.90	1.11	1.12	1.63	0.38*	1.61	1.84	1.81	2.22	0.17	0.28	0.44	0.60
		73	0.94	1.18	1.29	1.94	0.56**	1.54	1.74	1.88	2.28	0.26	0.61	0.81	2.40
		74	0.93	1.40	1.83	2.50	0.68**	1.53	2.18	2.21	2.61	0.27	0.91	0.95	1.85
		75	0.92	1.16	1.36	1.83	0.42**	1.54	1.86	1.99	2.74	0.33	0.56	0.75	1.78
		76	0.87	1.08	1.34	1.88	0.53**	1.51	1.67	1.89	2.94	0.27	0.58	0.96	1.96
		77	0.90	1.18	1.60	2.03	0.57**	1.58	1.83	1.94	3.92	0.29	0.45	0.59	2.84
	15-30	73	0.76	0.72	0.55	0.66	n.s.	1.13	1.52	1.46	1.05	0.09	0.15	0.25	0.02
		74	0.86	0.67	0.66	0.81	n.s.	1.26	1.74	1.39	1.42	0.14	0.18	0.32	0.30
		75	0.77	0.67	0.58	0.81	n.s.	1.07	1.72	1.52	1.22	0.18	0.16	0.31	0.15
		76	0.79	0.65	0.49	0.62	n.s.	1.08	1.47	1.17	1.31	0.16	0.29	0.18	0.27
		77	0.72	0.66	0.55	0.79	n.s.	1.21	1.55	1.47	1.43	0.12	0.20	0.21	0.82
	South Series														
	0-15	71	1.19	1.29	1.38	1.63	0.30*	1.51	1.52	1.71	2.06	0.36	0.31	0.43	0.73
		72	1.01	1.06	1.15	1.28	0.23**	1.34	1.40	1.57	2.00	0.17	0.44	0.51	0.57
		73	0.93	1.10	1.29	1.59	0.27**	1.29	1.35	1.57	1.76	0.21	0.63	0.94	1.30
		74	1.05	1.29	1.58	1.90	0.16**	1.45	1.58	1.79	2.67	0.42	0.67	1.16	1.42
		75	1.07	1.17	1.75	2.56	0.49**	1.30	1.54	1.93	2.72	0.44	0.78	1.40	2.40
		76	0.96	1.34	2.10	2.43	0.35**	1.30	1.64	2.09	3.53	0.56	0.80	1.75	2.76
		77	1.07	1.45	2.08	3.06	0.56**	1.41	1.69	2.37	3.35	0.48	0.99	2.00	3.44

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
Organic-C															
	South Series														
	15-30	74	0.68	0.72	0.83	0.81	n.s.	1.20	1.01	1.23	1.50	0.12	0.09	0.24	0.20
		75	0.70	0.78	0.86	0.84	n.s.	1.26	1.22	1.47	1.45	0.17	0.14	0.18	0.26
		76	0.68	0.66	0.85	0.61	n.s.	1.16	1.36	1.29	1.58	0.17	0.08	0.12	0.25
		77	0.78	0.88	0.90	0.75	n.s.	1.19	1.16	1.43	1.33	0.13	0.18	0.39	0.32
Total N															
	North Series														
	0-15	71	0.08	0.12	0.14	0.18	0.04**	0.14	0.15	0.19	0.24	0.03	0.06	0.08	0.18
		72	0.09	0.10	0.13	0.15	0.03**	0.15	0.17	0.16	0.19	0.02	0.03	0.05	0.06
		73	0.09	0.12	0.13	0.15	n.s.	0.15	0.16	0.17	0.22	0.02	0.06	0.07	0.21
		74	0.09	0.12	0.15	0.22	0.06**	0.14	0.18	0.18	0.23	0.03	0.07	0.07	0.13
		75	0.09	0.11	0.13	0.16	0.04**	0.14	0.16	0.17	0.24	0.03	0.04	0.06	0.13
		76	0.07	0.10	0.11	0.15	0.04**	0.12	0.13	0.14	0.26	0.02	0.04	0.06	0.17
		77	0.09	0.11	0.14	0.18	0.05**	0.14	0.16	0.18	0.39	0.02	0.04	0.06	0.21
	15-30	73	0.07	0.08	0.07	0.08	n.s.	0.11	0.14	0.13	0.11	0.01	0.02	0.03	0.02
		74	0.09	0.07	0.07	0.08	n.s.	0.11	0.15	0.12	0.13	0.01	0.01	0.02	0.02
		75	0.08	0.07	0.07	0.08	n.s.	0.10	0.14	0.13	0.11	0.02	0.02	0.02	0.02
		76	0.09	0.08	0.06	0.08	n.s.	0.11	0.13	0.12	0.14	0.01	0.03	0.02	0.02
		77	0.09	0.08	0.07	0.09	n.s.	0.10	0.15	0.13	0.17	0.01	0.02	0.02	0.07

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Total N															
	North Series														
	30-46	72	0.06	0.07	0.08	0.07		0.07	0.08	0.08	0.07	0.02	<0.01	0.01	0.02
		73	0.06	0.07	0.07	0.05		0.06	0.07	0.05	0.05	0.01	0.01	<0.01	<0.01
		74	0.06	0.06	0.06	0.06		0.06	0.08	0.08	0.05	<0.01	<0.01	<0.01	0.01
		75	0.07	0.06	0.06	0.05		0.06	0.08	0.08	0.07	<0.01	0.01	<0.01	0.01
		76	0.07	0.07	0.06	0.06		0.06	0.09	0.08	0.08	<0.01	0.01	<0.01	0.01
		77	0.08	0.07	0.07	0.07		0.07	0.09	0.09	0.10	<0.01	0.01	0.01	0.02
	61-76	72	0.05	0.06	0.07	0.06		0.05	0.06	0.05	0.06	0.01	0.01	0.01	0.01
		73	0.06	0.06	0.05	0.06		0.05	0.07	0.05	0.06	0.01	0.01	0.01	0.01
		74	0.05	0.06	0.04	0.05		0.06	0.06	0.04	0.05	0.01	<0.01	0.01	<0.01
		75	0.05	0.05	0.05	0.05		0.05	0.06	0.04	0.06	0.01	<0.01	<0.01	0.01
		76	0.05	0.04	0.04	0.05		0.05	0.05	0.04	0.05	0.01	<0.01	0.01	0.01
		77	0.05	0.07	0.05	0.06		0.06	0.05	0.06	0.07	0.01	0.01	0.01	0.06
Total N															
	South Series														
	0-15	71	0.10	0.10	0.11	0.13	0.01**	0.13	0.14	0.16	0.17	0.02	0.02	0.02	0.07
		72	0.10	0.10	0.11	0.12	n.s.	0.13	0.13	0.15	0.18	0.02	0.04	0.05	0.05
		73	0.09	0.11	0.12	0.16	0.03**	0.13	0.13	0.14	0.16	0.03	0.06	0.09	0.08
		74	0.11	0.12	0.14	0.17	0.01**	0.13	0.15	0.16	0.22	0.04	0.05	0.11	0.11
		75	0.11	0.11	0.16	0.23	0.05**	0.14	0.16	0.17	0.24	0.03	0.04	0.06	0.13
		76	0.08	0.12	0.18	0.20	0.06**	0.12	0.14	0.18	0.17	0.03	0.04	0.06	0.12
		77	0.13	0.14	0.20	0.29	0.04**	0.13	0.16	0.22	0.33	0.04	0.09	0.16	0.28

(continued)

D.3

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 1/4 Max	 1/2 Max	 Max	 LSD	 Elliott silt loam Ck	 1/4 Max	 1/2 Max	 Max	 Plainfield loamy sand Ck	 1/4 Max	 1/2 Max	 Max
			------	------	------	------	------	------	------	%	------	------	------	------	------
Total N															
	South Series														
	15-30	73	0.07	0.08	0.09	0.08	n.s.	0.12	0.11	0.12	0.12	0.01	0.01	0.01	0.02
		74	0.06	0.07	0.08	0.07	n.s.	0.09	0.10	0.10	0.14	0.01	0.01	0.02	0.01
		75	0.07	0.08	0.09	0.08	n.s.	0.10	0.14	0.13	0.11	0.02	0.02	0.02	0.02
		76	0.08	0.07	0.09	0.08	n.s.	0.12	0.14	0.12	0.16	0.02	0.01	0.01	0.02
		77	0.09	0.08	0.08	0.09	n.s.	0.11	0.12	0.14	0.13	0.01	0.02	0.04	0.03
	30-46	72	0.06	0.07	0.07	0.07		0.08	0.08	0.06	0.01	0.01	0.01	0.02	0.01
		73	0.06	0.08	0.07	0.07		0.07	0.07	0.06	0.09	<0.01	<0.01	<0.01	<0.01
		74	0.06	0.06	0.06	0.07		0.08	0.06	0.08	0.11	0.01	<0.01	0.02	0.01
		75	0.06	0.05	0.07	0.06		0.06	0.08	0.08	0.07	0.01	0.01	0.01	0.01
		76	0.06	0.07	0.07	0.07		0.08	0.08	0.07	0.12	0.01	0.01	<0.01	0.01
		77	0.07	0.08	0.08	0.09		0.09	0.09	0.09	0.11	0.01	0.01	<0.01	0.02
	61-76	72	0.06	0.05	0.06	0.06		0.05	0.07	0.06	0.07	<0.01	<0.01	0.02	<0.01
		73	0.06	0.06	0.07	0.06		0.05	0.06	0.06	0.08	<0.01	0.01	0.01	0.01
		74	0.05	0.05	0.04	0.04		0.04	0.05	0.05	0.07	<0.01	<0.01	<0.01	<0.01
		75	0.04	0.06	0.07	0.06		0.05	0.06	0.04	0.06	0.01	<0.01	<0.01	0.01
		76	0.05	0.05	0.06	0.05		0.05	0.05	0.06	0.07	0.01	0.01	0.01	0.01
		77	0.07	0.07	0.08	0.07		0.06	0.07	0.07	0.08	0.01	0.01	0.01	0.01

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			---%												
P															
	North Series														
	0-15	71	0.07	0.10	0.13	0.20	0.03**	0.07	0.09	0.15	0.24	0.05	0.08	0.13	0.31
		72	0.08	0.13	0.14	0.19	0.07**	0.07	0.18	0.15	0.20	0.05	0.06	0.08	0.11
		73	0.07	0.10	0.13	0.22	0.07**	0.08	0.09	0.15	0.20	0.05	0.09	0.12	0.31
		74	0.08	0.12	0.16	0.24	0.06**	0.07	0.13	0.15	0.24	0.04	0.11	0.11	0.15
		75	0.09	0.11	0.13	0.21	0.03**	0.07	0.10	0.14	0.25	0.05	0.08	0.11	0.23
		76	0.07	0.11	0.13	0.21	0.04**	0.09	0.11	0.13	0.32	0.05	0.08	0.11	0.27
		77	0.07	0.10	0.14	0.25	0.04**	0.07	0.09	0.12	0.36	0.03	0.06	0.11	0.31
	15-30	73	0.05	0.08	0.05	0.07	n.s.	0.06	0.08	0.08	0.06	0.04	0.04	0.06	0.06
		74	0.05	0.07	0.05	0.07	n.s.	0.05	0.06	0.06	0.07	0.05	0.03	0.06	0.04
		75	0.05	0.06	0.04	0.06	n.s.	0.05	0.06	0.05	0.06	0.03	0.03	0.05	0.04
		76	0.05	0.06	0.04	0.06	n.s.	0.05	0.05	0.06	0.08	0.03	0.05	0.04	0.05
		77	0.04	0.06	0.04	0.04	n.s.	0.04	0.03	0.02	0.09	0.02	0.02	0.03	0.10
	30-46	72	0.06	0.06	0.06	0.07		0.08	0.06	0.05	0.07	0.02	0.03	0.02	0.05
		73	0.06	0.06	0.06	0.06		0.06	0.06	0.07	0.05	0.03	0.03	0.03	0.03
		74	0.03	0.04	0.04	0.04		0.03	0.04	0.04	0.03	0.02	0.02	0.02	0.03
		75	0.03	0.02	0.03	0.03		0.02	0.04	0.03	0.03	0.01	0.01	0.01	0.02
		76	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.03	0.01	0.01	0.01	0.01
		77	0.02	0.03	0.02	0.02		0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
P															
	North Series														
	61-76	72	0.06	0.08	0.07	0.06		0.08	0.05	0.07	0.05	0.02	0.03	0.02	0.04
		73	0.05	0.06	0.06	0.06		0.05	0.05	0.06	0.02	0.06	0.02	0.05	0.03
		74	0.02	0.02	0.02	0.02		0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03
		75	0.02	0.03	0.02	0.03		0.02	0.02	0.02	0.02	0.01	<0.01	0.01	0.01
		76	0.03	0.03	0.03	0.03		0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.02
		77	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02
	South Series														
	0-15	71	0.06	0.07	0.10	0.13	0.03**	0.07	0.08	0.09	0.11	0.04	0.07	0.04	0.13
		72	0.06	0.09	0.10	0.18	n.s.	0.06	0.10	0.10	0.14	0.03	0.08	0.08	0.08
		73	0.08	0.09	0.12	0.18	0.05**	0.09	0.08	0.11	0.13	0.04	0.09	0.14	0.13
		74	0.08	0.10	0.14	0.20	0.03**	0.08	0.09	0.12	0.23	0.05	0.08	0.16	0.20
		75	0.07	0.09	0.16	0.29	0.06**	0.07	0.10	0.13	0.25	0.05	0.10	0.17	0.37
		76	0.06	0.10	0.19	0.27	0.05**	0.06	0.09	0.14	0.36	0.06	0.08	0.21	0.31
		77	0.08	0.11	0.20	0.34	0.12**	0.08	0.11	0.18	0.34	0.06	0.11	0.17	0.41
	15-30	73	0.05	0.05	0.06	0.05	n.s.	0.06	0.05	0.07	0.07	0.03	0.03	0.04	0.04
		74	0.04	0.05	0.05	0.06	n.s.	0.05	0.05	0.05	0.08	0.03	0.03	0.04	0.03
		75	0.04	0.04	0.04	0.05	n.s.	0.05	0.03	0.05	0.06	0.03	0.02	0.03	0.03
		76	0.04	0.04	0.05	0.04	n.s.	0.05	0.08	0.05	0.11	0.03	0.02	0.03	0.05
		77	0.04	0.04	0.04	0.04	n.s.	0.04	0.05	0.04	0.06	0.02	0.04	0.05	0.04

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			---					%				--------------------------------------			
P															
	South Series														
	30-46	72	0.04	0.04	0.04	0.05		0.04	0.06	0.05	0.06	0.02	0.02	0.04	0.03
		73	0.05	0.05	0.06	0.05		0.05	0.05	0.05	0.06	0.02	0.02	0.03	0.03
		74	0.03	0.03	0.03	0.03		0.03	0.03	0.04	0.05	0.02	0.02	0.02	0.02
		75	0.03	0.03	0.03	0.02		0.03	0.03	0.03	0.04	0.01	0.01	0.02	0.01
		76	0.03	0.03	0.03	0.03		0.03	0.04	0.03	0.06	0.02	0.01	0.02	0.01
		77	0.02	0.02	0.02	0.02		0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02
	61-76	72	0.04	0.05	0.04	0.05		0.04	0.05	0.04	0.05	0.02	0.02	0.02	0.03
		73	0.05	0.06	0.06	0.06		0.05	0.05	0.06	0.05	0.02	0.02	0.03	0.02
		74	0.03	0.02	0.02	0.02		0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.02
		75	0.03	0.02	0.03	0.03		0.02	0.03	0.03	0.03	0.01	0.01	0.01	0.02
		76	0.03	0.04	0.03	0.03		0.03	0.03	0.03	0.04	0.02	0.01	0.02	0.02
		77	0.02	0.02	0.02	0.02		0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
K															
	North Series														
	0-15	71	1.96	2.01	1.97	2.00	n.s.	1.77	1.78	1.86	1.76	1.06	1.34	1.23	1.19
		72	1.88	1.92	1.90	1.87	n.s.	1.82	1.80	1.80	1.71	1.20	1.16	1.03	1.16
		73	1.94	2.06	1.98	1.95	n.s.	1.86	1.87	1.97	1.92	1.14	1.36	1.14	1.36
		74	1.88	1.94	1.84	1.84	n.s.	1.78	1.75	1.78	1.73	1.00	1.20	1.06	0.83
		75	1.97	2.04	1.99	2.03	n.s.	1.88	1.90	1.89	1.84	1.32	1.21	1.20	1.21
		76	2.00	2.17	1.96	2.08	n.s.	1.97	2.02	2.06	1.94	1.24	1.30	1.12	1.17
		77	1.82	1.90	1.87	1.84	n.s.	1.77	1.83	1.73	1.69	1.06	1.08	1.22	1.25

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			---%												
K															
	North Series														
	15-30	73	1.87	2.03	1.82	1.57	n.s.	1.89	1.87	1.81	1.79	1.08	1.20	1.06	1.08
		74	1.73	1.87	1.75	1.67	n.s.	1.69	1.68	1.68	1.72	1.00	0.99	0.96	0.98
		75	1.96	2.10	1.96	1.91	n.s.	1.99	1.84	1.89	1.96	1.20	1.12	1.12	1.10
		76	2.00	2.22	2.10	1.99	n.s.	2.00	1.93	2.03	1.98	1.15	1.22	1.09	1.14
		77	1.84	1.85	1.78	1.76	n.s.	1.87	1.74	1.73	1.84	0.98	0.91	0.97	0.88
	30-46	72	2.03	2.28	2.16	1.83		2.15	2.12	2.06	1.94	0.92	0.95	0.91	1.06
		73	2.04	2.32	2.11	1.92		2.13	2.18	2.09	1.88	1.07	1.18	1.20	1.06
		74	1.77	2.26	2.06	1.72		2.06	1.84	1.92	1.76	0.90	0.92	0.89	0.94
		75	1.92	2.35	1.93	1.98		2.14	2.10	2.07	1.96	1.02	1.02	0.99	1.02
		76	2.05	2.31	2.04	1.93		2.10	2.08	2.19	1.93	0.92	1.07	1.00	1.03
		77	1.93	2.15	1.97	1.96		2.63	1.32	2.06	1.82	1.16	1.12	1.13	1.04
	61-76	72	2.01	2.70	2.31	2.26		2.27	2.43	2.18	1.82	0.95	0.95	0.95	1.08
		73	1.85	1.87	1.75	2.25		2.11	2.04	2.07	1.77	0.96	1.00	0.92	1.11
		74	1.54	1.94	1.78	1.70		1.88	1.74	1.79	1.32	0.72	0.79	0.76	0.74
		75	1.97	2.62	2.48	2.25		2.43	1.93	2.71	2.45	0.99	1.00	1.02	1.01
		76	1.97	2.28	2.38	2.08		2.61	2.55	2.30	1.93	0.99	0.95	1.01	1.11
		77	1.92	2.39	2.12	2.09		2.14	2.07	2.17	1.79	0.98	1.05	0.87	1.08

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
K															
	South Series														
	0-15	71	1.91	1.96	1.96	1.97	n.s.	1.77	1.82	1.86	1.81	1.38	1.37	0.91	1.41
		72	1.90	1.93	1.86	1.88	n.s.	1.79	1.75	1.75	1.74	0.98	1.14	1.03	1.03
		73	1.78	1.88	1.76	1.78	n.s.	1.69	1.67	1.76	1.70	1.05	1.12	1.12	0.91
		74	1.88	1.91	1.85	1.82	n.s.	1.73	1.80	1.73	1.76	1.15	1.06	1.18	1.08
		75	2.04	2.10	2.02	2.02	n.s.	1.90	2.00	1.95	1.92	1.29	1.38	1.19	1.38
		76	2.03	2.10	2.03	2.05	n.s.	1.93	1.90	2.01	1.93	1.64	1.20	1.39	1.26
		77	2.05	2.14	2.12	1.99	n.s.	1.98	1.87	2.00	1.94	1.36	1.08	1.25	1.20
	15-30	73	2.07	2.05	1.98	2.05	n.s.	1.84	1.90	1.83	1.96	1.02	1.02	0.98	1.06
		74	1.62	1.82	1.70	1.82	n.s.	1.69	1.75	1.78	1.81	1.06	0.97	0.98	0.81
		75	1.97	2.13	1.99	2.12	n.s.	1.86	1.91	1.96	1.94	1.10	1.09	1.07	1.13
		76	1.96	2.11	2.03	1.92	n.s.	1.85	1.87	2.02	1.98	1.10	1.00	1.00	1.11
		77	1.89	2.03	1.94	2.10	n.s.	1.77	1.98	1.86	1.76	0.97	1.07	1.15	0.91
	30-46	72	1.94	2.28	1.97	2.43		2.06	1.90	1.98	1.95	0.97	0.92	0.99	1.03
		73	1.91	2.31	2.05	2.24		2.08	1.79	1.84	1.87	0.93	0.86	0.96	0.97
		74	1.95	2.17	1.91	2.05		2.12	1.90	1.63	1.84	0.91	0.96	0.96	0.98
		75	2.09	2.27	2.07	2.37		2.19	2.00	1.91	1.97	1.06	1.03	0.98	1.09
		76	1.95	2.26	2.07	2.26		2.04	1.98	1.96	1.96	0.97	1.04	0.94	0.82
		77	1.83	2.31	2.01	2.26	0.27*	2.05	1.93	1.94	2.07	1.07		1.10	1.03

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
K															
	South Series														
	61-76	72	2.51	2.48	2.52	2.37		2.50	2.57	2.20	2.44	1.01	0.95	1.03	0.92
		73	2.50	2.59	2.72	2.41		2.56	2.85	2.20	2.79	1.04	1.09	1.07	1.07
		74	2.29	2.28	2.32	2.15		1.94	2.48	2.16	2.64	1.01	0.93	1.06	1.03
		75	2.60	2.62	2.48	2.59		2.58	2.70	2.28	2.36	1.02	1.12	1.02	1.05
		76	2.31	2.46	2.50	2.62		2.43	2.65	2.38	2.38	1.13	0.94	1.19	1.04
		77	2.60	2.90	2.80	2.80		2.68	2.96	2.08	2.71	0.92	0.84	0.83	0.87
Na															
	North Series														
	0-15	71	0.72	0.73	0.76	0.72	n.s.	0.80	0.76	0.81	0.72	0.51	0.68	0.66	0.55
		72	0.71	0.69	0.75	0.71	n.s.	0.75	0.77	0.73	0.61	0.57	0.56	0.52	0.57
		73	0.76	0.73	0.77	0.71	n.s.	0.80	0.78	0.78	0.74	0.57	0.62	0.51	0.65
		74	0.70	0.66	0.71	0.67	n.s.	0.72	0.72	0.69	0.69	0.48	0.57	0.54	0.42
		75	0.76	0.75	0.79	0.79	n.s.	0.79	0.83	0.81	0.75	0.64	0.55	0.57	0.53
		76	0.70	0.69	0.69	0.69	n.s.	0.77	0.75	0.73	0.70	0.54	0.55	0.48	0.51
		77	0.69	0.58	0.65	0.59	n.s.	0.66	0.65	0.60	0.60	0.48	0.51	0.53	0.51
	15-30	73	0.82	0.72	0.78	0.80	n.s.	0.82	0.84	0.81	0.73	0.57	0.61	0.56	0.62
		74	0.84	0.70	0.76	0.82	0.09*	0.76	0.82	0.77	0.79	0.57	0.55	0.57	0.57
		75	0.84	0.72	0.78	0.78	n.s.	0.76	0.84	0.80	0.78	0.58	0.55	0.55	0.56
		76	0.76	0.70	0.72	0.73	n.s.	0.74	0.78	0.69	0.69	0.54	0.55	0.52	0.56
		77	0.77	0.58	0.63	0.67	0.13 *	0.69	0.75	0.64	0.73	0.47	0.40	0.44	0.55

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Na															
	North Series														
	30-46	72	0.72	0.56	0.61	0.60	n.s.	0.64	0.67	0.56	0.64	0.51	0.52	0.49	0.57
		73	0.75	0.59	0.61	0.69	n.s.	0.69	0.65	0.62	0.81	0.62	0.66	0.56	0.57
		74	0.73	0.52	0.55	0.60	n.s.	0.63	0.68	0.57	0.68	0.49	0.49	0.47	0.54
		75	0.71	0.56	0.59	0.65	n.s.	0.62	0.75	0.64	0.69	0.53	0.52	0.51	0.55
		76	0.69	0.52	0.56	0.60	n.s.	0.59	0.60	0.48	0.65	0.47	0.54	0.51	0.50
		77	0.70	0.46	0.46	0.61	0.17*	0.67	0.39	0.43	0.63	0.55	0.53	0.53	0.46
	61-76	72	0.71	0.55	0.61	0.63	n.s.	0.56	0.61	0.44	0.71	0.55	0.52	0.52	0.54
		73	0.67	0.58	0.64	0.58	n.s.	0.61	0.58	0.50	0.55	0.57	0.50	0.61	0.66
		74	0.77	0.46	0.59	0.63	n.s.	0.55	0.64	0.45	0.74	0.52	0.57	0.52	0.53
		75	0.72	0.51	0.65	0.56	n.s.	0.55	0.60	0.44	0.81	0.53	0.53	0.53	0.52
		76	0.51	0.41	0.58	0.50	n.s.	0.46	0.48	0.34	0.76	0.53	0.48	0.51	0.55
		77	0.61	0.39	0.53	0.52	n.s.	0.43	0.39	0.38	0.68	0.57	0.52	0.44	0.52

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			--%--------------------------------												
Na															
	South Series														
	0-15	71	0.76	0.68	0.72	0.71	n.s.	0.79	0.78	0.78	0.79	0.51	0.45	0.52	0.52
		72	0.74	0.70	0.72	0.66	n.s.	0.77	0.77	0.77	0.73	0.51	0.58	0.55	0.51
		73	0.76	0.73	0.72	0.76	n.s.	0.79	0.77	0.79	0.80	0.57	0.62	0.60	0.47
		74	0.68	0.67	0.68	0.65	n.s.	0.74	0.77	0.81	0.68	0.58	0.55	0.52	0.54
		75	0.79	0.71	0.74	0.69	0.06*	0.80	0.77	0.78	0.79	0.58	0.62	0.57	0.58
		76	0.70	0.68	0.68	0.67	n.s.	0.76	0.76	0.80	0.74	0.64	0.57	0.58	0.55
		77	0.68	0.65	0.66	0.64	n.s.	0.73	0.68	0.72	0.94	0.60	0.50	0.56	0.55
	15-30	73	0.72	0.72	0.76	0.72	n.s.	0.75	0.78	0.77	0.77	0.52	0.52	0.54	0.56
		74	0.67	0.62	0.73	0.62	n.s.	0.77	0.78	0.77	0.72	0.57	0.55	0.56	0.45
		75	0.82	0.66	0.78	0.71	n.s.	0.80	0.81	0.79	0.79	0.52	0.52	0.53	0.55
		76	0.72	0.65	0.73	0.64	n.s.	0.76	0.74	0.76	0.74	0.51	0.51	0.53	0.54
		77	0.71	0.63	0.69	0.67	n.s.	0.70	0.73	0.69	0.64	0.50	0.54	0.56	0.49
	30-46	72	0.67	0.57	0.59	0.55	n.s.	0.66	0.71	0.65	0.71	0.55	0.57	0.53	0.57
		73	0.61	0.55	0.61	0.55	n.s.	0.63	0.72	0.71	0.73	0.51	0.49	0.53	0.54
		74	0.61	0.50	0.48	0.48	0.08*	0.58	0.60	0.61	0.63	0.48	0.53	0.53	0.51
		75	0.55	0.49	0.59	0.57	n.s.	0.63	0.66	0.61	0.68	0.55	0.54	0.54	0.56
		76	0.54	0.44	0.51	0.47	n.s.	0.61	0.58	0.67	0.73	0.49	0.56	0.53	0.42
		77	0.58	0.53	0.59	0.51	n.s.	0.64	0.62	0.70	0.71	0.51	0.48	0.57	0.50

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Na															
	South Series														
	61-76	72	0.61	0.49	0.51	0.49	0.08*	0.50	0.50	0.55	0.53	0.57	0.55	0.59	0.50
		73	0.53	0.50	0.55	0.42	n.s.	0.55	0.58	0.61	0.51	0.53	0.56	0.54	0.55
		74	0.52	0.44	0.47	0.38	0.07*	0.45	0.50	0.58	0.50	0.50	0.49	0.54	0.54
		75	0.56	0.53	0.51	0.53	n.s.	0.56	0.57	0.59	0.55	0.52	0.60	0.53	0.55
		76	0.46	0.42	0.46	0.44	n.s.	0.48	0.55	0.52	0.48	0.68	0.50	0.65	0.58
		77	0.58	0.51	0.51	0.48	n.s.	0.52	0.52	0.59	0.57	0.53	0.47	0.43	0.44
Ca															
	North Series														
	0-15	71	1.35	1.37	1.28	1.22		0.69	0.82	0.84	0.80	0.64	0.52	0.42	0.54
		73	1.41	1.79	1.56	1.80		0.94	0.96	1.30	1.14	0.52	0.48	0.72	0.80
		74	1.46	1.24	1.02	1.43		0.78	0.75	0.81	0.66	0.32	0.52	0.46	0.43
		75	1.33	1.26	1.02	1.24		0.68	0.67	0.99	0.67	0.42	0.42	0.46	0.47
		76	1.25	1.46	1.24	1.65		0.90	1.03	1.10	0.84	0.56	0.52	0.52	0.61
		77	1.14	1.26	1.03	1.25		0.67	0.77	0.91	0.87	0.28	0.45	0.54	0.60
	15-30	73	0.65	0.72	0.21	0.54		0.68	0.55	0.38	0.88	0.25	0.45	0.34	0.28
		74	0.76	0.74	0.46	0.48		0.55	0.55	0.70	0.74	0.39	0.44	0.42	0.35
		75	0.70	0.71	0.41	0.46		0.82	0.48	0.59	1.09	0.38	0.32	0.38	0.29
		76	0.79	0.66	0.68	0.82		1.12	0.70	0.93	1.34	0.44	0.58	0.34	0.41
		77	0.76	0.66	0.41	0.45		0.92	0.53	0.70	0.74	0.31	0.30	0.23	0.52

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Ca															
	North Series														
	30-46	73	0.52	0.37	0.65	0.57		1.14	0.80	0.77	1.17	0.55	0.49	0.57	0.38
		74	0.45	0.55	0.35	0.40		0.91	0.65	0.85	1.29	0.31	0.27	0.27	0.26
		75	0.41	0.64	0.40	0.49		0.44	0.49	1.18	1.34	0.25	0.24	0.24	0.24
		76	0.70	0.73	0.55	0.65		—	0.71	—	1.66	0.26	0.34	0.27	0.32
		77	0.56	0.72	0.42	0.38		1.06	0.36	0.60	0.99	0.29	0.29	0.35	0.23
	61-76	73	1.25	1.22	1.35	1.20		1.10	1.20	1.76	0.24	0.66	0.26	0.28	0.33
		74	0.52	1.31	0.87	0.78		1.21	1.03	2.38	0.39	0.30	0.16	0.28	0.28
		75	0.78	1.87	0.82	0.99		1.81	1.16	2.19	0.46	0.25	0.24	0.24	0.26
		76	0.74	1.39	1.27	0.88		1.95	1.17	2.90	0.40	0.38	0.23	0.20	0.25
		77	0.60	1.25	0.98	0.64		1.62	0.98	2.60	0.44	0.27	0.30	0.21	0.36
	South Series														
	0-15	71	0.95	0.98	1.02	0.94		0.64	0.61	0.62	0.48	0.33	0.30	0.34	0.42
		73	1.20	1.07	1.22	1.02		0.58	0.58	0.53	0.44	0.34	0.39	0.46	0.36
		74	1.51	1.55	1.40	1.38		0.63	0.66	0.61	0.66	0.40	0.42	0.44	0.48
		75	1.08	1.48	1.16	1.42		0.58	0.66	0.60	0.58	0.40	0.48	0.50	0.65
		76	1.48	1.52	1.48	1.45		0.73	0.70	0.75	0.78	0.39	0.56	0.63	0.62
		77	0.94	1.27	1.36	1.37		0.44	0.72	0.68	0.60	0.54	0.47	0.64	0.59

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Ca															
	South Series														
	15-30	73	0.47	0.42	0.46	0.47		0.83	0.47	0.59	0.42	0.26	0.28	0.32	0.24
		74	0.61	0.64	0.44	0.57		0.56	0.68	0.66	0.54	0.32	0.28	0.41	0.27
		75	0.50	0.78	0.59	0.85		0.62	0.46	0.48	0.48	0.29	0.30	0.35	0.31
		76	1.08	0.78	0.67	0.91		0.68	0.67	0.67	0.53	0.47	0.35	0.33	0.34
		77	0.59	0.65	0.71	0.51		0.56	0.51	0.60	0.45	0.34	0.38	0.53	0.26
	30-46	73	0.39	0.33	0.40	0.39		0.56	0.65	0.35	0.71	0.29	0.22	0.24	0.21
		74	0.42	0.47	0.44	0.53		0.60	0.73	0.70	0.68	0.28	0.29	0.32	0.34
		75	0.34	0.57	0.36	0.43		0.66	0.92	0.93	0.68	0.26	0.26	0.24	0.29
		76	0.70	0.41	0.44	0.54		0.66	1.15	1.33	0.54	0.42	0.36	0.27	0.20
		77	0.41	0.35	0.40	0.36		0.71	0.58	0.74	0.74	0.26	0.24	0.30	0.22
	61-76	73	0.87	1.18	0.48	0.93		0.52	0.33	0.84	0.28	0.20	0.32	0.22	0.20
		74	0.91	1.36	0.71	1.68		0.55	0.41	0.54	0.37	0.30	0.33	0.12	0.16
		75	1.00	1.41	0.46	1.57		0.96	0.41	0.56	0.36	0.26	0.29	0.43	0.24
		76	0.81	0.76	0.73	2.04		0.96	0.82	0.55	0.41	0.31	0.24	0.32	0.28
		77	0.74	1.18	0.48	1.80		0.94	0.39	0.44	0.53	0.26	0.43	0.23	0.20

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Mg															
	North Series														
	0-15	71	0.87	0.86	0.87	0.92	n.s.	0.54	0.63	0.66	0.60	0.19	0.28	0.19	0.51
		73	0.81	0.98	0.81	0.91	n.s.	0.57	0.50	0.68	0.53	0.17	0.21	0.23	0.35
		74	0.87	0.88	0.68	0.85	n.s.	0.49	0.53	0.58	0.47	0.16	0.24	0.20	0.22
		75	0.87	0.84	0.72	0.79	n.s.	0.49	0.48	0.70	0.51	0.23	0.21	0.22	0.22
		76	0.79	0.94	0.73	0.94	n.s.	0.50	0.61	0.69	0.54	0.25	0.25	0.23	0.27
		77	0.74	0.85	0.71	0.80	n.s.	0.49	0.57	0.61	0.60	0.15	0.25	0.28	0.36
	15-30	73	0.61	0.62	0.45	0.43	n.s.	0.52	0.31	0.58	0.59	0.12	0.18	0.15	0.13
		74	0.58	0.67	0.53	0.43	n.s.	0.55	0.44	0.61	0.59	0.17	0.22	0.20	0.16
		75	0.56	0.68	0.53	0.48	n.s.	0.65	0.40	0.52	0.83	0.21	0.17	0.17	0.14
		76	0.60	0.67	0.67	0.65	n.s.	0.79	0.48	0.72	0.86	0.23	0.27	0.15	0.20
		77	0.64	0.73	0.49	0.48	n.s.	0.71	0.43	0.61	0.64	0.18	0.17	0.13	0.21
	30-46	73	0.75	0.47	0.59	0.73	0.13 *	0.76	0.74	1.04	1.02	0.19	0.17	0.17	0.19
		74	0.57	0.77	0.58	0.58		0.93	0.66	0.80	0.94	0.13	0.11	0.10	0.12
		75	0.50	0.80	0.68	0.74		0.68	0.68	1.17	0.95	0.12	0.12	0.11	0.12
		76	0.68	0.85	0.73	0.77		0.93	0.72	0.84	1.13	0.12	0.18	0.13	0.12
		77	0.57	0.72	0.61	0.54		0.89	0.36	0.69	0.76	0.14	0.14	0.18	0.12
	61-76	73	0.96	1.33	0.73	0.97		0.97	1.04	1.60	0.63	0.13	0.09	0.12	0.11
		74	0.76	1.23	0.96	1.02		0.62	1.03	1.85	0.66	0.14	0.10	0.17	0.13
		75	0.92	1.52	0.92	1.03		1.29	1.16	1.83	0.64	0.09	0.11	0.11	0.12
		76	0.78	1.20	1.08	0.91		1.33	1.02	1.76	0.68	0.10	0.12	0.12	0.15
		77	0.67	1.02	0.97	0.78		1.26	0.76	1.49	0.63	0.12	0.14	0.10	0.18

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt laom					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
									%						
Mg															
	South Series														
	0-15	71	0.87	0.88	0.95	0.92	n.s.	0.53	0.49	0.45	0.48	0.25	0.24	0.11	0.30
		73	0.80	0.76	0.82	0.74	n.s.	0.48	0.43	0.39	0.28	0.16	0.20	0.28	0.18
		74	0.85	0.88	0.82	0.82	n.s.	0.46	0.49	0.42	0.41	0.20	0.20	0.32	0.21
		75	0.78	1.05	0.79	0.93	n.s.	0.49	0.55	0.47	0.44	0.23	0.27	0.29	0.35
		76	0.93	0.92	0.90	0.90	n.s.	0.48	0.47	0.51	0.51	0.22	0.29	0.36	0.32
		77	0.88	0.89	0.91	0.92	n.s.	0.36	0.58	0.51	0.45	0.33	0.28	0.37	0.33
	15-30	73	0.49	0.62	0.55	0.58	n.s.	0.65	0.46	0.51	0.87	0.11	0.11	0.10	0.13
		74	0.56	0.64	0.45	0.60	n.s.	0.47	0.58	0.36	0.48	0.15	0.13	0.21	0.13
		75	0.57	0.62	0.57	0.74	n.s.	0.52	0.48	0.41	0.47	0.15	0.15	0.17	0.17
		76	0.71	0.66	0.61	0.70	n.s.	0.48	0.47	0.49	0.46	0.24	0.17	0.16	0.17
		77	0.54	0.64	0.60	0.57	n.s.	0.48	0.46	0.43	0.36	0.19	0.20	0.32	0.21
	30-46	73	0.82	0.79	0.84	0.82		0.86	0.82	0.99	0.84	0.12	0.11	0.10	0.09
		74	0.75	0.79	0.68	0.81		0.83	0.84	0.69	0.64	0.11	0.13	0.14	0.12
		75	0.71	0.81	0.67	0.92		0.89	0.89	0.79	0.68	0.12	0.12	0.12	0.14
		76	0.75	0.68	0.63	0.76		0.72	0.85	0.92	0.61	0.21	0.18	0.12	0.10
		77	0.73	0.83	0.71	0.82		0.81	0.75	0.74	0.74	0.12	0.12	0.14	0.13
	61-76	73	0.91	0.97	0.85	0.78		0.81	0.76	0.87	0.79	0.10	0.15	0.08	0.06
		74	1.22	1.33	1.09	1.33		0.83	0.96	0.99	0.81	0.15	0.13	0.09	0.11
		75	1.21	1.35	0.99	1.36		1.27	0.97	0.86	0.96	0.11	0.12	0.13	0.12
		76	0.72	0.80	0.83	1.19		0.87	0.93	0.77	0.60	0.11	0.09	0.13	0.11
		77	1.13	1.35	0.99	1.03		1.22	0.97	0.87	1.00	0.12	0.20	0.10	0.08

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Fe															
	North Series														
	0-15	71	2.72	2.71	2.51	2.78	n.s.	2.46	2.55	2.60	2.92	0.74	1.16	0.91	1.13
		72	2.41	2.16	2.10	2.27	n.s.	2.26	2.25	2.29	2.48	0.74	0.68	0.69	0.84
		73	2.68	2.52	2.74	3.00	n.s.	2.65	2.54	2.95	2.74	0.83	0.88	0.88	1.52
		74	2.83	2.90	2.72	2.90	n.s.	2.83	2.72	2.90	2.72	0.76	1.26	0.84	1.00
		75	2.61	2.71	2.61	2.78	n.s.	2.56	2.68	2.77	2.92	0.90	0.90	1.04	1.22
		76	2.51	2.41	2.44	2.48	n.s.	2.37	2.55	2.63	2.74	0.86	0.87	0.80	1.12
		77	2.36	2.54	2.38	2.60	n.s.	2.33	2.49	2.44	2.83	0.74	0.84	1.03	1.39
	15-30	73	2.09	2.33	2.14	2.02	n.s.	2.36	1.90	1.99	2.17	0.60	0.80	0.46	0.80
		74	2.47	3.42	2.92	2.44	n.s.	2.96	2.64	2.95	2.75	0.78	0.84	0.79	0.80
		75	2.38	3.27	2.73	2.47	n.s.	3.07	2.31	2.60	2.94	0.84	0.71	0.74	0.70
		76	2.40	2.86	2.84	2.52	n.s.	2.60	2.27	2.98	2.82	0.68	0.79	0.56	0.76
		77	2.54	3.00	2.80	2.47	n.s.	2.58	2.55	2.75	2.93	0.73	0.53	0.51	0.61
	30-46	72	2.96	4.18	3.61	3.43		3.36	3.77	3.70	2.74	0.50	0.63	0.50	0.75
		73	2.98	3.50	3.27	3.40		2.98	3.43	3.18	2.44	0.59	0.77	0.80	0.54
		74	3.67	3.54	4.34	3.76		4.36	3.79	4.49	3.42	0.61	0.56	0.57	0.32
		75	3.26	4.30	4.04	3.99		3.47	4.33	4.47	3.03	0.63	0.65	0.57	0.65
		76	3.40	4.49	4.14	3.81		3.88	4.00	4.43	3.33	0.56	0.74	0.60	0.60
		77	3.25	4.25	3.86	3.62		4.39	2.50	4.33	2.93	0.64	0.59	0.61	0.56

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Fe															
	North Series														
	61-76	72	3.71	3.86	3.53	4.12		3.51	4.24	3.41	3.97	0.53	0.57	0.55	0.66
		73	4.81	4.17	4.31	3.96		4.50	5.18	4.31	3.12	0.62	0.50	0.53	0.71
		74	4.48	4.55	3.47	4.91		4.16	5.68	5.42	3.96	0.63	0.34	0.77	0.61
		75	4.02	3.81	4.25	3.91		3.67	4.52	3.88	3.51	0.55	0.59	0.56	0.62
		76	4.15	3.95	4.47	4.24		4.33	5.27	3.54	4.09	0.61	0.57	0.60	0.56
		77	4.12	4.60	4.23	4.34		4.07	5.22	3.84	3.69	0.82	0.71	0.68	0.92
	South Series														
	0-15	71	2.39	2.51	2.56	2.56	n.s.	2.38	2.42	2.30	2.40	1.07	1.12	0.64	1.32
		72	2.18	2.29	2.08	2.36	n.s.	2.16	2.18	2.12	2.20	0.73	1.12	0.90	0.94
		73	2.95	3.02	2.78	3.27	n.s.	2.70	2.52	3.22	3.22	0.94	1.17	1.28	1.17
		74	2.45	2.70	2.57	2.75	n.s.	2.33	2.51	2.16	2.69	0.97	0.97	1.30	0.97
		75	2.38	2.62	2.55	2.72	n.s.	2.43	2.59	2.40	2.61	0.92	1.13	1.08	1.61
		76	2.26	2.43	2.48	2.47	n.s.	2.21	2.27	2.24	2.57	1.70	0.97	1.34	1.31
		77	2.43	2.66	2.64	2.66	n.s.	2.36	2.37	2.43	2.59	1.10	1.04	1.35	1.55
	15-30	73	2.56	2.31	2.07	2.30	n.s.	2.18	2.19	2.28	2.38	0.61	0.74	0.65	0.64
		74	2.63	2.97	2.59	2.99	n.s.	2.60	2.39	3.10	2.65	0.69	0.70	0.78	0.67
		75	2.56	2.94	2.44	2.78	n.s.	2.33	2.52	2.22	2.56	0.76	0.65	0.68	0.76
		76	2.42	2.69	2.42	2.65	n.s.	2.19	2.19	2.07	2.33	0.67	0.56	0.58	0.69
		77	2.17	2.50	2.43	2.67	n.s.	2.30	2.48	1.96	2.20	0.76	0.86	0.98	0.75

(continued)

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TABLE 7. (continued)

Parameter	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			%												
Fe															
	South Series														
	30-46	72	3.38	3.73	3.30	3.90		3.23	3.04	3.44	2.83	0.62	0.67	0.67	0.71
		73	3.87	4.35	4.37	4.34		3.85	3.22	3.22	3.64	0.80	0.65	0.69	0.87
		74	3.74	3.92	3.79	4.19		3.88	3.81	3.08	3.00	0.66	0.68	0.68	0.65
		75	4.04	4.39	3.54	4.05		3.79	3.48	3.18	3.03	0.64	0.64	0.63	0.72
		76	3.60	4.29	3.91	4.30		3.49	3.37	3.01	2.98	0.63	0.73	0.55	0.43
		77	3.09	4.04	3.37	3.99		3.11	3.28	2.80	2.77	0.53	0.50	0.50	0.58
	61-76	72	3.02	3.92	4.16	3.59		4.03	4.49	4.09	4.09	0.61	0.53	0.70	0.62
		73	3.83	3.67	3.75	3.14		3.28	2.86	4.09	3.43	0.62	0.61	0.80	0.58
		74	3.56	3.52	3.91	3.33		3.66	3.76	3.99	3.98	0.66	0.61	0.72	0.73
		75	4.26	4.11	4.44	4.18		4.29	4.51	4.30	4.58	0.60	0.69	0.62	0.67
		76	4.33	4.46	4.60	4.39		4.38	4.49	4.77	4.62	0.54	0.43	0.71	0.57
		77	4.17	3.94	4.26	3.99		3.98	4.26	4.31	4.21	0.39	0.42	0.27	0.22

(continued)

p.20

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			---ppm---												
Mn															
	North Series														
	0-15	71	783	762	898	802	n.s.	770	760	654	1101	237	280	189	238
		72	867	891	943	950	n.s.	972	872	863	1072	264	173	124	193
		73	911	837	1134	1063	n.s.	936	857	817	1115	216	301	171	338
		74	1039	967	1204	1048	n.s.	1322	1160	895	1124	214	268	234	268
		75	1081	1108	1263	1256	n.s.	1156	1200	1082	1222	258	253	204	276
		76	903	951	1306	1176	n.s.	1178	1386	1178	1258	278	250	175	275
		77	920	838	1182	1100	n.s.	1059	1072	830	1054	190	213	245	319
	15-30	73	824	711	725	970	n.s.	750	905	949	986	184	215	147	197
		74	1242	869	960	1244	n.s.	924	1243	842	1262	252	192	153	197
		75	1111	931	903	1075	n.s.	1002	1128	895	1168	253	184	166	162
		76	1208	970	915	962	n.s.	1005	1090	918	1137	219	256	150	191
		77	1079	857	991	1012	n.s.	869	1203	1118	1257	167	130	96	182
	30-46	72	673	588	466	450		573	743	502	832	106	120	105	155
		73	774	570	556	483		684	665	594	918	156	168	155	119
		74	769	772	727	506		754	911	747	947	158	130	119	160
		75	1002	713	634	653		610	932	856	1209	182	162	141	162
		76	824	690	706	567		730	836	610	1057	142	191	133	146
		77	818	589	539	510		569	558	596	1000	137	106	127	99

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Mn															
	North Series														
	61-76	72	708	641	627	732		640	743	578	527	132	128	130	163
		73	726	733	630	581		663	661	610	470	147	114	118	173
		74	776	731	745	686		750	934	591	451	156	140	170	159
		75	779	736	777	722		695	777	747	767	142	139	128	162
		76	777	731	760	690		624	803	643	584	153	126	158	148
		77	791	672	729	597		688	726	626	515	132	140	91	167
	South Series														
	0-15	71	824	792	762	726	n.s.	804	721	674	749	258	244	141	316
		72	968	941	900	791	n.s.	890	835	657	747	184	301	197	177
		73	963	1026	950	930	n.s.	858	798	754	798	196	232	223	176
		74	1190	1165	1144	1014	n.s.	1046	1007	904	934	301	252	338	284
		75	1292	1111	1187	928	n.s.	995	931	852	958	304	326	294	398
		76	1100	1019	1125	953	n.s.	1012	952	814	918	258	325	382	332
		77	1195	1100	1065	917	n.s.	1013	863	808	859	378	312	399	360
	15-30	73	840	720	829	694	n.s.	816	667	795	795	142	152	152	131
		74	1072	929	1127	860	n.s.	1091	781	824	883	190	161	210	125
		75	906	1014	986	940	n.s.	939	855	864	860	273	169	174	200
		76	1090	980	1091	906	n.s.	951	795	965	795	196	150	144	166
		77	995	999	1118	948	n.s.	928	764	846	895	208	193	325	157

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Mn															
	South Series														
	30–46	72	387	425	421	483		557	570	471	696	170	147	157	171
		73	374	434	419	466		436	488	457	589	136	100	100	139
		74	501	627	556	681	118*	611	530	655	830	158	145	181	147
		75	232	487	458	581	189*	534	693	628	715	160	130	135	152
		76	590	576	567	625		686	599	669	886	178	179	142	106
		77	586	562	510	506		690	592	557	823	171	129	140	146
	61–76	72	611	604	578	603		596	623	495	508	148	146	159	126
		73	598	560	608	544		575	546	514	597	120	116	152	122
		74	745	744	710	714		668	754	690	605	168	135	175	170
		75	717	691	669	765		736	747	591	638	156	156	162	151
		76	740	750	702	798		687	763	543	599	165	101	195	126
		77	619	716	627	691		676	678	521	529	137	118	109	168
Zn															
	North Series														
	0–15	71	72	138	195	319	47**	64	127	226	418	40	130	244	500
		72	83	124	167	257	31**	81	136	179	259	30	70	117	180
		73	82	130	168	327	106**	75	132	207	315	33	102	168	449
		74	79	169	270	451	139**	75	185	228	386	23	158	175	248
		75	84	143	201	314	39**	73	152	210	375	33	104	165	323
		76	73	154	200	319	29**	70	143	214	468	21	104	139	374
		77	72	157	227	361	52**	66	151	200	582	24	93	166	472

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Zn															
	North Series														
	15-30	73	79	84	75	75	n.s.	67	78	100	88	23	31	63	62
		74	86	112	94	81	n.s.	88	102	123	122	20	35	90	68
		75	78	89	78	81	n.s.	79	91	88	111	29	44	70	54
		76	71	82	71	70	n.s.	71	73	99	139	23	58	49	70
		77	74	80	69	69	n.s.	61	70	78	151	23	34	31	136
	30-46	72	92	125	98	92		101	119	92	94	42	32	17	48
		73	97	105	97	94		103	136	88	106	42	36	32	18
		74	85	111	98	82		87	96	108	82	15	19	19	24
		75	89	112	97	101		93	126	126	90	26	17	32	17
		76	82	113	96	90		87	116	108	103	19	21	31	21
		77	91	117	96	82		95	72	102	94	20	19	24	26
	61-76	72	97	109	98	121		99	118	85	94	16	34	22	47
		73	87	99	92	91		88	128	92	87	33	17	18	22
		74	97	114	108	115		111	142	105	90	15	15	16	17
		75	103	103	106	117		92	117	96	102	20	17	20	20
		76	94	97	107	107		108	135	86	91	20	16	19	21
		77	102	119	106	105		103	123	106	95	20	18	14	20

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Zn															
	South Series														
	0-15	71	73	106	174	241	55**	85	102	159	215	55	61	60	265
		72	72	103	122	220	30**	68	105	131	215	24	88	122	133
		73	67	113	166	270	94**	84	96	143	193	22	125	192	227
		74	72	147	196	308	56**	70	138	171	333	32	111	243	293
		75	69	150	250	432	91**	74	156	216	368	43	165	238	506
		76	68	188	326	454	75**	79	206	270	553	46	149	336	500
		77	72	184	348	528	38**	80	180	294	543	55	193	335	589
	15-30	73	65	68	68	76	n.s.	63	66	71	82	18	28	34	30
		74	70	94	80	110	n.s.	81	81	90	130	19	26	62	40
		75	67	75	73	84	10*	67	74	83	107	25	40	47	50
		76	63	79	75	71	n.s.	62	104	82	149	27	18	29	91
		77	66	73	85	86	12*	69	88	86	119	25	52	82	75
	30-46	72	102	90	82	101		101	78	104	107	21	24	26	37
		73	75	88	81	99		85	101	79	78	16	15	15	17
		74	84	99	86	96		91	83	86	112	17	19	21	24
		75	93	93	91	101		86	90	90	107	20	25	23	32
		76	79	97	92	101		81	105	77	131	20	21	15	22
		77	80	97	87	106		80	97	76	84	16	14	20	30

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 1/4 Max	 1/2 Max	 Max	 LSD	 Elliott silt loam Ck	 1/4 Max	 1/2 Max	 Max	 Plainfield loamy sand Ck	 1/4 Max	 1/2 Max	 Max
			ppm												
Zn															
	South Series														
	61-76	72	103	98	101	101		98	114	104	114	21	17	22	24
		73	95	92	110	89		95	102	96	106	22	20	22	20
		74	113	108	115	110		109	122	114	124	19	16	19	22
		75	108	100	109	112		104	116	98	105	17	17	17	23
		76	102	103	103	106		100	116	104	127	16	12	19	16
		77	109	110	114	107		108	123	105	110	17	13	15	17
Cd															
	North Series														
	0-15	71	0.57	4.14	7.65	14.89	2.92**	<.25	3.33	7.72	17.65	<0.25	5.08	11.65	28.15
		72	0.50	1.49	3.37	8.72	2.79**	<.25	2.53	4.13	8.36	0.62	1.87	3.96	7.08
		73	0.37	2.95	5.13	12.28	5.35**	0.34	3.48	6.62	13.87	1.35	5.14	9.04	22.67
		74	0.48	4.59	8.50	17.30	5.20**	<.25	4.55	7.38	15.53	0.40	5.47	7.78	10.22
		75	0.40	3.00	6.10	11.10	1.70**	0.81	3.60	6.64	16.46	0.32	3.51	6.34	15.63
		76	0.35	3.46	5.73	12.37	2.49**	0.27	3.76	6.75	20.90	0.35	3.58	5.61	18.23
		77	0.80	3.70	7.10	14.20	2.80**	0.74	4.49	7.34	30.77	0.48	3.57	7.66	24.15
	15-30	73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	2.77	1.16
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	.81	<.25	<.25	1.96	1.39
		75	0.51	0.30	<.25	<.25		<.25	0.26	<.25	.52	.40	1.06	1.88	1.38
		76	<.25	<.25	<.25	<.25		<.25	<.25	0.44	3.38	<.25	1.61	1.86	2.76
		77	<.25	<.25	<.25	0.59		<.25	<.25	<.25	4.63	<.25	0.99	1.50	8.06

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cd															
	North Series														
	30-46	72	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	0.38	<.25	0.72	0.72
		73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	0.62	0.29	0.73
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		75	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		76	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		77	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
	61-76	72	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		75	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		76	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		77	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
	South Series														
	0-15	71	0.74	2.52	4.59	8.47	3.87**	0.74	2.36	3.65	6.66	0.93	3.37	5.69	9.57
		72	<.25	1.58	2.62	5.90	3.49**	<.25	1.36	2.09	5.57	<.25	3.02	4.38	5.84
		73	0.27	3.78	6.00	11.36	3.28**	0.50	2.59	5.36	6.59	0.39	5.91	9.81	12.72
		74	0.57	3.78	6.13	11.76	1.33**	<.25	3.01	4.70	11.96	0.78	4.13	8.48	13.19
		75	<.25	3.60	8.72	21.12	5.60**	0.36	4.17	7.26	15.89	0.58	5.89	9.38	27.88
		76	0.32	6.25	12.73	20.56	5.75**	0.58	5.64	8.01	25.26	0.89	6.29	15.71	22.59
		77	0.53	6.55	15.24	27.82	3.63**	0.69	6.21	13.16	25.53	1.18	9.62	16.60	31.37

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cd															
	South Series														
	15-30	73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	0.37
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	0.81	<.25	<.25	1.11	0.41
		75	0.38	0.52	0.46	0.56		0.43	0.35	0.45	1.78	0.46	0.38	2.14	1.73
		76	<.25	<.25	0.38	0.37		<.25	1.99	0.68	3.79	<.25	<.25	0.46	2.55
		77	<.25	<.25	0.67	0.37		<.25	0.83	0.32	--	<.25	1.55	2.76	3.22
	30-46	72	<.25	<.25	<.25	<.25		<.25	<.25	<.25	0.63	<.25	<.25	<.25	<.25
		73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	0.54	0.43	<.25	<.25
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		75	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		76	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		77	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
	61-76	72	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		73	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		74	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		75	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		76	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25
		77	<.25	<.25	<.25	<.25		<.25	<.25	<.25	<.25	<.25	<.25	<.25	<.25

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cu															
	North Series														
	0-15	71	22	42	60	102	16**	19	39	65	150	10	36	68	154
		72	20	28	38	65	11**	27	32	41	64	9	14	36	42
		73	28	42	57	91	28**	26	39	64	92	12	27	47	118
		74	22	40	67	116	37**	20	32	62	112	5	37	47	60
		75	24	42	56	91	9**	22	44	59	117	12	28	46	104
		76	21	38	49	88	12**	18	38	56	151	8	26	37	116
		77	25	45	64	106	16**	23	49	61	222	10	25	52	164
	15-30	73	22	24	23	21	n.s.	22	21	26	25	7	7	20	18
		74	22	28	25	21	n.s.	23	22	28	28	8	11	20	17
		75	23	32	22	23	n.s.	27	24	31	32	9	14	22	16
		76	19	25	22	22	n.s.	21	18	28	42	6	15	14	21
		77	24	29	25	24	n.s.	23	22	25	51	9	10	15	58
	30-46	72	22	37	32	26	10*	24	33	30	21	6	12	7	13
		73	30	36	35	35		35	45	30	46	19	16	10	5
		74	24	37	32	26		32	27	33	27	12	7	12	6
		75	36	46	60	45		39	41	47	32	8	11	13	8
		76	25	35	31	29		30	34	36	34	4	5	14	4
		77	26	37	31	26		36	22	35	27	6	8	8	12

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			units												
Cu															
	North Series														
	61-76	72	31	38	30	36		30	52	29	32	5	4	10	14
		73	36	37	39	37		32	46	34	28	5	6	14	18
		74	31	42	33	37		35	39	34	27	5	8	5	3
		75	38	40	45	50		39	49	42	43	7	15	10	10
		76	33	33	36	37		36	46	31	31	4	4	4	5
		77	31	38	34	35		34	39	42	29	6	4	4	4
	South Series														
	0-15	71	20	30	44	66	13**	19	30	38	60	7	23	35	61
		72	15	24	27	50	16**	13	20	28	50	7	23	26	33
		73	19	35	45	76	19**	18	27	41	56	6	33	53	73
		74	20	39	52	78	14**	19	36	46	90	9	28	57	77
		75	22	47	75	133	29**	22	52	64	115	14	45	65	162
		76	20	57	103	136	25**	19	50	80	171	6	42	99	155
		77	23	63	112	180	62**	20	54	96	171	14	62	111	199
	15-30	73	23	21	18	26		18	20	19	25	4	10	11	7
		74	20	24	19	20		21	24	26	23	6	7	16	14
		75	19	25	25	31		24	22	23	34	8	13	14	16
		76	19	23	23	22		18	31	22	47	6	4	9	21
		77	17	21	22	25		18	28	20	23	6	14	22	24

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cu															
South Series															
	30-46	72	25	27	24	30		24	26	31	29	8	8	9	13
		73	27	33	29	36	5*	28	31	24	30	7	5	4	5
		74	27	30	27	30		29	27	26	30	6	5	7	9
		75	33	33	31	34		37	33	28	33	5	7	6	12
		76	34	36	37	37	2*	36	37	37	42	3	4	5	4
		77	25	32	28	35		25	29	23	24	3	2	5	7
	61-76	72	32	31	34	30		26	35	34	33	10	9	9	8
		73	35	35	37	34		35	39	33	41	3	4	5	4
		74	34	34	36	33		34	39	37	38	4	3	4	6
		75	39	38	44	43		44	44	38	47	12	10	8	8
		76	25	32	29	34		25	31	23	41	4	5	4	4
		77	37	38	40	38		38	44	37	37	3	16	5	3
Ni															
North Series															
	0-15	71	24	28	28	37	7*	18	24	29	37	17	16	16	43
		72	27	20	19	30	n.s.	23	24	40	40	14	22	24	34
		73	30	35	44	42	n.s.	30	26	27	36	14	15	18	32
		74	31	42	35	44	n.s.	28	38	36	44	10	16	15	14
		75	25	25	21	36	9**	23	26	26	41	15	17	22	32
		76	27	33	28	37	7**	25	30	34	49	14	16	15	32
		77	22	26	26	33	3**	18	22	26	60	8	9	15	38

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Ni															
	North Series														
	15-30	73	23	26	28	18	n.s.	29	26	26	32	8	11	13	17
		74	22	29	22	21	n.s.	25	19	28	30	10	14	10	6
		75	24	25	18	20	n.s.	24	19	20	23	10	12	12	10
		76	24	29	26	24	n.s.	27	21	27	33	11	13	9	12
		77	20	23	20	17	n.s.	20	18	19	26	5	5	7	13
	30-46	73	31	36	32	37	n.s.	48	51	35	29	9	12	10	10
		74	22	25	26	22	n.s.	30	22	32	23	11	11	11	11
		75	27	37	34	29	n.s.	38	32	38	29	8	9	8	9
		76	32	41	35	32	n.s.	39	34	42	35	9	13	13	10
		77	24	33	38	23	n.s.	32	18	37	25	7	7	9	9
	61-76	73	36	56	42	42	n.s.	35	55	56	42	6	4	6	7
		74	29	43	36	39	n.s.	47	41	51	24	6	8	7	6
		75	46	47	57	40	n.s.	44	54	54	60	12	9	9	10
		76	34	39	41	39	n.s.	42	46	38	29	7	8	8	10
		77	36	46	43	39	n.s.	44	41	45	28	10	9	8	9

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			ppm												
Ni															
	South Series														
	0-15	71	22	26	29	31	5*	20	22	22	27	11	15	13	21
		72	25	33	32	41	n.s.	24	32	29	27	12	31	20	37
		73	25	29	28	38	9*	25	22	24	30	8	12	16	16
		74	33	36	36	45	n.s.	31	39	41	41	13	12	22	34
		75	21	29	36	48	17**	20	32	35	44	16	20	24	40
		76	27	35	45	52	10**	38	31	37	52	33	19	35	45
		77	28	35	45	60	10**	23	32	39	55	15	25	37	49
	15-30	73	26	31	21	30	7**	28	26	31	30	14	14	14	14
		74	24	29	21	31	n.s.	31	41	29	24	6	6	11	11
		75	21	25	20	26	5*	21	25	24	25	9	10	11	9
		76	32	30	24	27	n.s.	23	24	25	28	11	10	8	18
		77	21	24	22	24	n.s.	20	23	19	23	7	13	16	9
	30-46	73	28	39	29	27	n.s.	39	35	32	37	4	6	4	9
		74	23	35	25	32	n.s.	32	26	23	32	8	9	6	9
		75	29	36	27	39	10**	29	30	28	26	7	8	10	9
		76	24	31	26	36	9*	21	28	26	19	1	8	3	10
		77	27	36	27	39	7*	28	23	32	26	7	6	7	7

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 1/4 Max	 1/2 Max	 Max	 LSD	 Elliott silt loam Ck	 1/4 Max	 1/2 Max	 Max	 Plainfield loamy sand Ck	 1/4 Max	 1/2 Max	 Max
			ppm												
Ni															
	South Series														
	61-76	72	68	70	74	65		74	90	71	72	11	10	11	12
		73	57	68	70	55	n.s.	62	70	61	71	11	14	13	10
		74	44	48	50	40	n.s.	52	57	41	48	7	10	12	13
		75	53	50	56	59	n.s.	60	63	46	54	8	10	9	10
		76	51	58	58	56	n.s.	51	62	45	44	5	8	8	8
		77	49	57	54	54	n.s.	56	55	37	46	7	10	7	5
Cr															
	North Series														
	0-15	71	39	74	109	180	50**	31	64	121	216	22	67	129	273
		72	36	57	74	135	44**	37	73	96	145	16	38	56	93
		73	50	73	116	176	63**	40	65	106	174	23	48	83	226
		74	35	75	97	199	30**	34	73	99	188	25	58	83	99
		75	54	82	114	175	24**	42	74	116	242	31	59	103	218
		76	48	82	99	175	17**	41	74	112	248	22	55	69	224
		77	45	75	107	180	19**	38	88	102	294	16	43	91	268
	15-30	73	42	50	48	43	5*	40	48	48	48	10	25	25	32
		74	43	50	49	53	n.s.	41	42	60	58	13	27	38	27
		75	39	42	41	42	n.s.	41	39	40	58	14	25	36	25
		76	35	41	38	40	n.s.	41	33	45	49	13	32	20	36
		77	35	39	37	38	n.s.	38	34	38	51	13	28	22	61

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 1/4 Max	 1/2 Max	 Max	 LSD	 Elliott silt loam Ck	 1/4 Max	 1/2 Max	 Max	 Plainfield loamy sand Ck	 1/4 Max	 1/2 Max	 Max
			ppm												
Cr															
	North Series														
	30-46	72	62	69	78	51		70	70	56	52	7	20	9	18
		73	62	55	67	79		73	83	61	50	10	13	11	7
		74	41	43	48	47		44	36	64	43	8	10	9	12
		75	50	62	62	60		61	57	80	60	13	13	13	14
		76	48	54	51	53		55	45	61	66	11	14	11	11
		77	41	49	47	41		49	27	50	44	7	10	10	8
	61-76	72	53	58	57	62		55	58	47	56	6	9	9	13
		73	62	46	61	58		53	59	63	68	8	6	8	12
		74	43	51	47	49		49	49	51	39	7	6	5	8
		75	57	68	66	61		61	61	80	60	12	11	12	13
		76	65	75	73	71		85	70	88	62	15	17	14	17
		77	45	54	53	50		58	50	65	45	11	13	8	13
	South Series														
	0-15	71	36	54	71	110	27**	31	53	65	91	12	29	47	115
		72	28	50	56	96	38**	27	42	51	106	13	37	60	75
		73	47	83	95	150	39**	47	64	85	106	22	68	106	136
		74	40	71	93	142	26**	35	65	83	149	19	52	102	169
		75	47	103	146	329	54**	48	84	117	235	29	97	151	341
		76	48	116	117	275	56**	48	99	99	311	15	87	183	327
		77	48	86	198	325	66**	45	94	145	272	34	105	189	344

(continued)

TABLE 7. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Parameter	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cr															
	South Series														
	15-30	73	41	49	37	48	n.s.	35	30	40	44	5	6	23	10
		74	37	41	33	37	n.s.	49	62	49	51	14	18	30	14
		75	36	46	42	49	n.s.	34	37	32	59	15	15	25	18
		76	44	47	43	46	n.s.	34	61	40	53	15	12	16	25
		77	34	39	41	40	8**	31	40	30	69	13	25	38	39
	30-46	72	53	57	50	59		53	66	69	64	10	13	8	13
		73	69	72	72	78		64	61	57	71	17	20	20	17
		74	47	54	52	56		53	53	64	61	16	13	12	10
		75	60	64	58	63		59	60	53	59	14	13	12	13
		76	61	70	66	71		59	72	59	52	16	18	12	6
		77	44	37	49	39		43	50	40	42	28	54	11	10
	61-76	72	61	60	59	57		64	64	62	71	2	7	11	13
		73	55	53	60	50		56	54	68	54	6	9	12	9
		74	50	51	53	50		50	49	56	56	9	8	12	11
		75	62	65	67	66		68	69	65	69	12	13	12	16
		76	58	62	61	72		62	66	65	72	11	9	15	11
		77	56	58	57	62	4*	59	56	48	56	8	9	5	6

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 1/4 Max	 1/2 Max	 Max	 LSD	 Elliott silt loam Ck	 1/4 Max	 1/2 Max	 Max	 Plainfield loamy sand Ck	 1/4 Max	 1/2 Max	 Max
			ppm												
Pb															
	North Series														
	0-15	71	32	52	60	83	21**	31	42	59	107	24	35	61	119
		72	23	34	41	61	8**	20	37	42	67	8	16	25	36
		73	27	36	54	81	24**	27	43	54	80	11	32	40	111
		74	36	57	78	118	29**	34	62	69	106	13	47	47	69
		75	32	47	62	92	27**	32	52	63	108	18	37	44	79
		76	33	48	63	94	13**	35	56	66	127	15	37	40	100
		77	32	43	61	97	17**	29	48	54	134	13	29	57	117
	15-30	73	22	24	22	24	n.s.	23	29	29	27	8	6	15	20
		74	31	32	31	31	n.s.	30	31	36	35	12	13	22	18
		75	26	27	23	21	n.s.	24	38	28	34	6	15	16	16
		76	25	28	23	28	n.s.	30	26	35	39	7	23	16	20
		77	26	29	32	31	n.s.	26	29	29	47	9	13	9	40
	30-46	72	22	28	25	23		24	24	27	23	6	7	9	7
		73	25	26	25	28		21	29	27	26	6	6	3	5
		74	31	38	30	35		34	34	30	31	10	12	15	15
		75	29	32	32	30		27	34	34	30	10	8	11	10
		76	32	31	29	30		30	35	31	35	6	10	9	13
		77	25	27	23	22		24	21	26	28	4	6	4	5

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			ppm												
Pb															
	North Series														
	61-76	72	28	32	29	43		26	38	32	28	9	13	9	8
		73	30	27	28	29		27	34	32	31	12	5	14	8
		74	32	29	27	31		29	46	29	31	10	10	8	9
		75	26	27	30	28		27	30	30	29	8	8	8	9
		76	27	27	30	32		30	34	24	30	4	3	2	3
		77	32	27	34	30		34	36	26	28	9	10	7	10
	South Series														
	0-15	71	32	36	48	61	11**	35	37	48	61	8	24	20	56
		72	29	35	44	62	22**	28	39	41	69	9	26	28	32
		73	30	40	49	68	14**	27	35	45	49	9	30	46	59
		74	29	44	61	85	10**	28	43	52	96	8	28	54	76
		75	29	40	60	115	30**	25	27	52	99	18	38	63	138
		76	28	56	91	120	21**	30	50	71	155	27	39	74	134
		77	21	62	102	150	18**	42	57	82	143	26	58	96	159
	15-30	73	23	19	23	24	n.s.	22	18	21	23	4	5	12	5
		74	24	20	31	35	n.s.	32	29	33	41	9	10	18	12
		75	34	41	39	40	n.s.	39	24	32	46	20	24	24	20
		76	26	33	29	27	n.s.	25	40	24	48	5	2	5	21
		77	34	37	37	36	n.s.	37	39	38	33	16	[illegible]3	27	23

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type Blount silt loam Ck	 Blount silt loam 1/4 Max	 Blount silt loam 1/2 Max	 Blount silt loam Max	LSD	 Elliott silt loam Ck	 Elliott silt loam 1/4 Max	 Elliott silt loam 1/2 Max	 Elliott silt loam Max	 Plainfield loamy sand Ck	 Plainfield loamy sand 1/4 Max	 Plainfield loamy sand 1/2 Max	 Plainfield loamy sand Max
			ppm												
Pb															
	South Series														
	30-46	72	25	24	22	31		24	26	26	35	5	5	8	6
		73	22	26	28	28		24	23	23	32	10	10	6	11
		74	24	30	31	38		29	24	26	26	10	15	19	10
		75	26	28	22	35		27	30	26	31	11	8	10	10
		76	25	27	30	28		27	28	26	44	6	5	3	2
		77	25	31	24	33		30	27	17	26	2	6	6	10
	61-76	72	27	36	30	25		28	30	28	24	3	7	5	5
		73	20	20	25	20		25	24	20	20	11	4	6	6
		74	29	32	31	27		27	29	29	32	12	13	8	10
		75	27	30	28	27		28	29	26	34	11	10	11	11
		76	31	26	28	22		34	36	36	25	10	6	5	2
		77	27	25	28	25		28	32	27	32	2	4	2	2

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			--units--												
pH															
	North Series														
	0-15	71	7.8	7.7	7.6	7.6	n.s.	7.6	7.3	7.8	7.5	7.8	7.6	7.5	7.6
		72	6.9	6.9	7.0	6.8	n.s.	6.8	6.8	7.0	6.4	7.1	7.1	6.9	6.6
		73	7.6	7.5	7.4	7.3	n.s.	7.2	7.1	7.3	6.5	7.3	7.4	7.1	6.8
		74	7.6	7.5	7.3	7.2	n.s.	7.2	7.1	7.3	6.5	6.8	7.3	6.8	6.5
		75	7.8	7.6	7.5	7.3	n.s.	7.0	7.2	7.4	6.5	7.6	7.4	7.1	6.1
		76	7.5	7.5	7.2	7.2	n.s.	7.0	7.2	7.3	5.9	7.5	7.1	7.1	6.2
		77	7.6	7.7	7.4	7.3	0.2*	7.4	7.5	7.4	5.9	7.5	7.5	6.9	6.0
	15-30	73	6.8	6.5	5.4	6.1	n.s.	7.2	6.2	6.8	6.9	7.0	7.4	6.9	6.5
		74	6.6	6.7	5.7	5.8	n.s.	7.0	6.6	7.1	6.6	7.2	7.5	6.8	6.5
		75	7.3	7.2	6.2	6.3	0.9*	7.6	7.1	7.2	7.3	7.6	7.4	7.4	6.4
		76	6.9	6.9	6.3	6.1	n.s.	7.2	6.7	7.0	6.7	7.5	7.5	6.5	6.4
		77	7.4	6.9	5.6	6.0	1.0*	7.4	6.9	6.7	7.4	7.3	7.5	7.4	7.3
	30-46	72	5.9	5.4	4.6	4.9	n.s.	7.0	5.9	5.4	6.7	7.2	7.0	6.8	7.3
		73	6.3	6.4	5.6	5.6	n.s.	7.2	6.8	6.9	7.5	7.2	7.5	6.7	7.0
		74	5.5	5.9	5.1	4.8	n.s.	6.8	6.8	6.7	7.3	7.4	7.2	6.4	6.4
		75	6.5	7.0	5.8	5.8	n.s.	6.7	6.9	7.1	7.5	7.6	7.3	7.2	6.6
		76	6.4	7.0	6.0	5.9	n.s.	7.2	7.0	6.2	7.3	7.4	7.4	6.8	6.5
		77	5.0	5.7	4.4	4.0	n.s.	5.4	6.2	5.8	6.5	6.3	6.9	6.8	5.8

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			units												
pH															
	North Series														
	61-76	72	6.3	6.7	6.1	6.7		6.7	6.6	7.1	4.6	7.0	7.4	6.1	6.9
		73	6.7	7.5	6.8	6.8		7.3	7.3	7.8	5.1	5.8	6.8	5.6	7.2
		74	5.5	7.4	6.6	5.8		7.0	6.8	7.4	4.7	7.0	7.2	6.4	6.5
		75	6.4	7.5	6.7	6.9		7.2	7.2	8.0	5.3	7.5	7.5	7.1	7.1
		76	6.4	7.4	6.5	6.2		7.6	7.2	7.9	4.6	6.9	7.0	6.3	6.4
	South Series														
	0-15	72	7.1	7.2	7.1	6.9	n.s.	7.0	6.9	6.9	6.4	7.0	7.2	7.1	6.8
		73	7.5	7.6	7.6	7.5	n.s.	7.2	7.2	7.3	6.4	7.2	7.3	7.0	6.7
		74	7.7	7.6	7.6	7.5	n.s.	7.1	7.4	7.1	6.2	7.1	7.5	7.2	6.6
		75	7.3	7.6	7.5	7.3	n.s.	7.6	7.1	6.9	6.1	7.0	7.0	7.0	6.4
		76	7.5	7.4	7.0	6.9	.34**	7.0	6.9	6.6	5.4	6.9	7.0	6.4	6.1
		77	7.3	7.2	6.9	6.8	.39**	7.2	6.9	6.4	5.5	7.0	6.6	6.3	5.8
	15-30	73	6.2	6.2	6.4	6.2	n.s.	7.3	6.8	7.0	6.0	6.8	7.3	7.2	6.5
		74	6.7	6.7	6.0	6.4	n.s.	6.6	7.0	7.0	6.1	7.2	7.4	7.2	6.1
		75	7.2	7.3	6.8	7.5	n.s.	7.6	7.2	7.1	6.7	7.4	7.6	7.5	7.4
		76	7.4	6.4	6.3	6.9	n.s.	7.1	6.8	6.8	5.5	7.4	7.6	7.0	6.1
		77	6.2	5.8	6.0	6.1	n.s.	7.0	6.3	6.7	5.7	6.9	7.3	7.0	5.7

(continued)

TABLE 7. (continued)

Parameter	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			----------------------------------units----------------------------------												
pH															
	South Series														
	30-46	72	4.9	4.8	4.8	4.9		6.5	6.1	6.5	6.2	7.4	5.9	6.2	6.1
		73	5.3	5.2	5.0	5.5		6.4	6.6	7.1	6.6	7.2	6.9	6.4	6.7
		74	5.1	5.8	5.6	5.8		6.5	6.3	6.7	6.6	7.1	7.0	6.9	5.8
		75	5.7	6.3	5.6	6.5		6.8	7.0	7.1	6.8	7.4	7.4	7.2	7.0
		76	7.0	5.9	5.4	6.4		6.9	7.2	7.2	6.1	7.5	7.6	6.7	5.5
		77													
	61-76	72	6.5	7.4	7.2	7.2		6.8	6.2	5.8	6.1	7.4	7.2	7.3	6.6
		73	7.2	7.7	6.6	7.5		6.4	6.3	6.5	5.8	7.2	7.4	7.3	6.8
		74	6.5	7.4	6.4	7.3		6.4	6.4	6.0	5.6	7.5	7.3	6.7	6.4
		75	7.3	7.6	6.6	7.4		7.3	6.8	6.6	5.9	7.5	7.5	7.6	6.7
		76	7.2	7.2	6.7	7.3		6.8	7.0	6.2	5.9	7.1	7.2	6.8	6.1

a/ In each series Blount silt loam control and sludge-treated plots were replicated three times. Sludge treatments on other soil types were not replicated within a series.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Elliott silt loam and Plainfield loamy sand maximum-sludge-treated plots in the north series, total N in soils tended to increase with successive years. In general, organic-C and total N concentration ratios varied from 10 to 13. At the time soil samples were taken each year, total N was almost equivalent to organic-N concentrations. Total P concentrations in the surface layer of soils were significantly increased by maximum sludge applications, but not in deeper soil depths. After sludge applications were terminated (north series, Blount silt loam) P concentrations remained fairly constant. Where sludge applications were continued (south series) maximum-and 1/2-maximum sludge treatments caused significant accumulations of P in soil surfaces with successive years of application.

Sewage sludges in general contain very low concentrations of K and Na and thus land applications did not produce measurable K and Na concentration increases in soils. Total soil concentrations of K and Na were lower in Plainfield loamy sand than in other soil types and the situation was not changed by sludge applications. Plainfield loamy sand contained less Ca and Mg than Elliott silt loam. The latter soil type contained less Ca and Mg in the surface layer than Blount silt loam soil. Evidently, the Blount silt loam soil had received a high lime application rate before the study was initiated, because none was applied during the study. In the absence of lime applications, Blount silt loam would have had a lower pH as well as lower concentrations of Ca and Mg than Elliott silt loam soil. Even though sludge applications added relatively high amounts of Fe (Table 2), concentrations of the element remained unchanged in soils. This finding could have been anticipated because soils generally contain more Fe than is found in sludge. Relative to amounts already present in soils, very little Mn was added to soils as a constituent of applied sludge (Table 2). Neither Fe nor Mn were at high enough concentrations in sludge to cause significant changes in soil concentrations. In comparison to amounts in normal soils, digested sewage sludge applications added relatively high amounts of Zn, Cd, Cu, Ni, Cr, and Pb to soils. Except for Ni, all of these metals were significantly increased in the soil surface by maximum sludge treatments. Due to large variations in soil sample contents, significant changes in Ni concentrations in maximum-sludge-treated soil surfaces were not always higher than those in control plots. Total concentrations of all metals remained unchanged in soil below the surface plow layer, except Ni, regardless of sludge application rates and soil type. Surface soil pH in maximum-sludge-treated Blount silt loam plots was significantly lower than in control plots during the last year for those in the north series and the last two years for those in the south series. Where sludge application continued past 1973 on maximum treated Elliott silt loam and Plainfield loamy sand, pH values tended to be lower in surface soil than those in corresponding control plots, but replication of these two soil types was inadequate for determining significant differences. Soil pH was significantly lowered by maximum sludge treatments in the 15 to 30 cm sampling depth of Blount silt loam plots during 2 of 5 years in the north series, but not in the south series. Soil pH values were not affected by sludge treatments at any depth below 30 cm for any soil type.

Changes in Extractable Concentrations of Inorganic Elements in Soils

Concentrations of several elements extracted from soils with 0.1 N HCl are shown in Table 8. These kind of data have frequently been used to estimate the availability of some chemical elements for uptake by plants, but is of little predictive value for other elements. For example, this extractant has been used with some success to predict the availability of P, Zn, and Cu for uptake by plants grown on some soil types, but the availability of Cr and Pb can not be predicted from the results of this kind of soil analysis.

Maximum sludge-treatments caused increased 0.1 N HCl extractable P concentrations in the surface of all soil types. Extractable P concentraions tended to increase by successive years of sludge application and in control plots as a result of superphosphate fertilizer applications. Differences in extractable P concentrations in soil zones below the surface, that could be attributed to sludge applications, were not observed. In 2 out of 4 years in each of the north and south series, 0.1 N HCl extractable K concentrations were increased by maximum sludge applications in the surface but not the subsoil of Blount silt loam soil. Extractable K concentrations tended to increase with sludge applications in the surface of other soil types. But contrary to extractable K, concentrations of extractable Na were significantly decreased in the surface of Blount silt loam soils by sludge applications. During the last two years in which such measurements were made, extractable Na concentrations were decreased in Blount silt loam soils by sludge applications to a depth of 30 to 46 cm. Results for extractable Na concentrations in other soil types tended to support the observation made from Blount silt loam. Concentration of 0.1 N HCl extractable Ca and Mg in soils were not affected by sludge treatments. Concentrations of 0.1 N HCl extractable Fe were too variable to make a rational interpretation of data due to effects of variable weather conditions prior to sample collection and rate of drying samples after collection, both of which magnify the normally expected high variation between samples. Nevertheless, some evidence was found in 1972 and 1974 that sludge applications did increase extractable Fe, even though total Fe contents were not affected by sludge treatments. Like Fe, concentrations of extractable Mn tended to be increased even though total amounts in soils were not appreciably affected by sludge applications. Also like Fe, amounts of extractable Mn appeared to be determined to a large extent by differences in weather conditions and methods of handling samples. Extractable Mn concentrations were increased 3 out of 4 years in the surface of maximum-sludge-treated Blount silt loam in the north, but not in the south series. Extractable concentrations of Zn, Cd, Cu, Ni, Cr, and Pb were significantly increased in surface soils (0-15 cm) by sludge applications. Ignoring the data for 1971, because sample collection and tillage methods were different from laters years, extractable concentrations of the latter elements tended to increase with successive years of sludge applications. However, as will be seen later, these elements did not increase in plant tissues in proportions corresponding to extractable levels in soils. Thus, because extractable levels did not predict concentrations in plant tissues these analyses were terminated after 1974.
(continued on Page 221)

TABLE 8. CONCENTRATIONS OF SELECTED 0.1 N HCl EXTRACTABLE CHEMICAL ELEMENTS IN SOIL SAMPLES FROM BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS.a/b/

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Element	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
P															
	North Series														
	0-15	1971	75	209	339	608	246**	64	168	523	814	146	409	663	888
		1972	150	367	401	656	340**	118	284	354	662	194	297	391	542
		1973	156	242	308	727	323**	93	210	352	704	243	438	694	1464
		1974	186	370	576	1092	556**	131	382	495	1079	216	647	725	1290
	15-30	1973	26	108	23	80		32	38	71	40	141	118	236	216
		1974	34	129	49	158		40	58	79	82	179	145	358	242
	30-46	1971	25	22	5	18		3	6	8	7	81	70	97	98
		1972	25	30	18	29		16	14	20	38	66	52	68	96
		1973	18	20	15	21		16	13	27	35	78	100	74	127
		1974	16	29	11	27		18	25	55	33	95	98	98	65
	61-76	1971	6	8	14	12		15	4	3	13	135	99	179	142
		1972	48	68	59	50		42	51	26	34	55	71	43	68
		1973	19	32	20	29		15	13	8	19	70	69	82	85

(continued)

TABLE 8. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Element	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
P															
	South Series														
	0-15	1971	63	56	153	355	128**	72	93	204	387	101	154	312	495
		1972	76	100	143	294	125**	100	113	144	416	152	220	463	355
		1973	90	115	238	532	156**	104	121	261	415	203	470	773	878
		1974	133	177	359	688	135**	155	212	378	994	163	370	765	1000
	15-30	1973	18	24	28	30		48	41	79	73	120	101	151	125
		1974	22	30	27	103		35	40	70	182	99	107	213	166
	30-46	1971	23	5	7	7		12	13	30	32	70	132	164	158
		1972	76	74	81	85		85	89	110	131	86	93	118	148
		1973	12	19	16	18		15	17	22	37	66	68	97	114
		1974	19	19	19	22		18	41	70	100	98	96	101	101
	61-76	1971	6	10	8	11		7	7	6	7	61	109	133	201
		1972	102	110	90	81		110	130	112	118	86	92	107	99
		1973	24	48	37	35		37	95	14	20	64	61	82	16
K															
	North Series														
	0-15	1971	306	368	381	416	57*	286	329	368	440	194	226	171	254
		1972	220	216	224	263		211	230	241	305	164	173	150	177
		1973	379	344	334	416		276	321	336	503	530	494	273	522
		1974	268	284	293	367	62*	230	329	293	429	266	347	261	293

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type: Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			ppm												
K															
	North Series														
	15-30	1973	160	168	202	161		160	140	145	204	145	116	135	142
		1974	134	164	177	144		153	143	143	184	175	160	147	132
	30-46	1971	181	207	219	216		232	207	233	170	96	101	113	138
		1972	167	200	203	166		188	121	218	186	78	97	76	122
		1973	263	290	353	294		224	260	282	219	80	111	63	98
		1974	212	217	234	234		240	195	180	213	132	129	124	262
	61-76	1971	238	283	261	241		206	409	182	245	119	97	109	146
		1972	194	234	218	205		206	183	264	194	67	95	75	114
		1973	296	257	210	256		190	172	77	320	160	107	211	78
	South Series														
	0-15	1971	299	321	326	363	41*	306	320	304	383	158	189	201	219
		1972	235	261	260	298		251	220	207	322	189	272	183	212
		1973	243	236	269	320	46**	226	227	242	270	194	254	275	246
		1974	288	258	275	295		249	264	256	317	212	268	248	259
	15-30	1973	227	204	164	210		131	149	147	204	178	178	123	134
		1974	148	179	139	202		146	143	145	201	250	310	211	85

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type Blount silt loam Ck	 Blount silt loam 1/4 Max	 Blount silt loam 1/2 Max	 Blount silt loam Max	LSD	 Elliott silt loam Ck	 Elliott silt loam 1/4 Max	 Elliott silt loam 1/2 Max	 Elliott silt loam Max	 Plainfield loamy sand Ck	 Plainfield loamy sand 1/4 Max	 Plainfield loamy sand 1/2 Max	 Plainfield loamy sand Max
			ppm												
K															
	South Series														
	30-46	1971	190	204	191	225		211	220	203	171	83	122	131	122
		1972	154	167	172	169		206	210	227	176	76	101	115	96
		1973	262	302	282	283		286	326	256	267	98	132	93	138
		1974	306	291	273	289		264	274	213	220	250	279	342	197
	61-76	1971	233	233	235	209		245	258	262	260	78	102	133	125
		1972	166	227	193	240		198	182	129	191	68	72	92	100
		1973	224	219	310	209	74*	262	110	306	502	72	147	130	277
Na															
	North Series														
	0-15	1971	111	37	45	60	14**	104	33	62	57	14	13	13	29
		1972	80	35	40	55	9**	88	33	57	59	22	12	12	18
		1973	87	50	56	58		84	42	58	66	56	38	25	42
		1974	51	32	28	43	16*	66	19	40	45	20	17	14	17
	15-30	1973	87	35	42	51	12**	94	22	59	69	10	9	16	14
		1974	87	42	47	57	22**	103	35	65	70	18	16	14	15
	30-46	1971	53	29	41	49		48	30	46	43	39	11	9	13
		1972	62	34	51	72	19**	60	33	53	64	24	15	12	19
		1973	98	48	66	78	35**	92	53	78	74	15	14	9	12
		1974	117	58	72	88	39**	120	46	86	99	16	21	14	43

(continued)

8.4

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Na															
	North Series														
	61-76	1971	46	37	48	45	7**	46	60	53	34	48	13	14	19
		1972	50	44	54	61		48	38	61	47	38	21	14	26
		1973	92	65	75	75	15*	78	59	84	72	40	20	45	18
	South Series														
	0-15	1971	96	42	45	50	11**	94	34	44	44	14	7	12	15
		1972	106	39	51	62	13**	115	29	42	60	22	14	13	14
		1973	74	36	41	45	24*	81	19	26	38	12	11	19	11
		1974	75	38	44	49	21**	86	33	40	38	22	22	19	23
	15-30	1973	117	42	51	69	35**	118	39	48	59	36	18	14	19
		1974	120	43	53	74	27**	132	40	53	56	34	40	24	11
	30-46	1971	51	27	30	39		49	31	39	37	24	10	8	12
		1972	71	27	53	64		92	38	56	72	55	15	15	12
		1973	102	43	53	68	36**	106	46	60	63	12	15	9	13
		1974	171	55	73	93	68**	148	51	62	80	54	47	55	28
	61-76	1971	40	39	37	53	10*	44	32	35	36	28	17	12	13
		1972	50	48	46	61		58	43	43	54	40	19	17	22
		1973	81	66	66	84		74	15	56	87	24	24	17	57

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type											
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Ca	North Series														
	0-15	1971	0.93	0.90	0.80	1.13		0.35	0.53	0.59	0.47	0.12	0.15	0.14	0.21
		1973	0.88	1.09	0.74	0.99		0.45	0.46	0.49	0.43	0.18	0.25	0.21	0.47
		1974	1.28	1.26	0.87	1.27		0.48	0.43	0.69	0.54	0.13	0.23	0.23	0.59
	15-30	1973	0.41	0.48	0.19	0.33		0.42	0.27	0.35	0.69	0.06	0.21	0.11	0.07
		1974	0.51	0.53	0.20	0.20		0.47	0.29	0.44	0.48	0.12	0.18	0.15	0.08
	30-46	1971	0.18	0.24	0.26	0.20		0.54	0.46	0.66	0.90	0.04	0.04	0.03	0.06
		1973	0.25	0.39	0.24	0.34		0.66	0.36	0.56	0.94	0.05	0.12	0.04	0.06
		1974	0.22	0.43	0.24	0.23		0.74	0.43	0.76	1.12	0.10	0.03	0.02	0.03
	61-76	1971	0.36	0.36	0.62	0.29		1.05	0.34	1.92	0.20	0.03	0.04	0.02	0.06
		1973	1.06	1.11	1.41	0.67		0.37	1.19	2.54	0.32	0.04	0.07	0.03	0.08
	South Series														
	0-15	1971	0.95	0.98	1.02	0.94		0.33	0.30	0.30	0.29	0.14	0.09	0.11	0.16
		1973	0.91	0.98	0.94	0.77		0.31	0.29	0.35	0.24	0.11	0.18	0.29	0.14
		1974	1.28	1.25	1.26	1.14		0.38	0.47	0.40	0.35	0.16	0.18	0.38	0.24

(continued)

TABLE 8. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Element	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			--					%				--------------------------------			
Ca															
	South Series														
	15-30	1973	0.31	0.28	0.22	0.24		0.68	0.25	0.37	0.22	0.05	0.07	0.08	0.04
		1974	0.44	0.47	0.23	0.42		0.31	0.46	0.50	0.26	0.06	0.05	0.13	0.06
	30-46	1971	0.17	0.18	0.18	0.20		0.41	0.61	0.65	0.40	0.03	0.07	0.06	0.06
		1973	0.24	0.23	0.36	0.39		0.36	0.49	0.49	0.50	0.03	0.02	0.02	0.03
		1974	0.27	0.35	0.33	0.36		0.45	0.51	0.50	0.45	0.04	0.03	0.05	0.03
	61-76	1971	0.21	0.46	0.31	1.18	0.70*	0.25	0.19	0.19	0.19	0.03	0.05	0.06	0.05
		1973	0.97	1.59	0.52	1.19		0.52	0.05	0.68	0.24	0.04	0.07	0.05	0.04
Mg															
	North Series														
	0-15	1971	0.43	0.39	0.37	0.44		0.15	0.23	0.24	0.17	0.04	0.05	0.04	0.11
		1973	0.34	0.34	0.27	0.35		0.14	0.15	0.15	0.12	0.07	0.10	0.07	0.13
		1974	0.45	0.41	0.27	0.40		0.12	0.11	0.15	0.12	0.04	0.07	0.07	0.17
	15-30	1973	0.15	0.16	0.07	0.12		0.14	0.07	0.10	0.28	0.03	0.07	0.04	0.03
		1974	0.11	0.14	0.04	0.05		0.17	0.05	0.12	0.16	0.04	0.06	0.05	0.02

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Mg															
	North Series														
	30-46	1971	0.07	0.09	0.13	0.09		0.25	0.21	0.28	0.43	0.01	0.02	0.01	0.03
		1973	0.18	0.14	0.10	0.13		0.25	0.14	0.22	0.36	0.02	0.04	0.02	0.02
		1974	0.07	0.14	0.09	0.08		0.30	0.15	0.28	0.47	0.04	0.01	<0.01	0.01
	61-76	1971	0.22	0.22	0.33	0.17		0.42	0.20	0.69	0.13	0.01	0.01	0.01	0.02
		1973	0.49	0.47	0.62	0.29		0.63	0.55	0.65	0.13	<0.01	0.01	0.02	0.01
	South Series														
	0-15	1971	0.40	0.42	0.42	0.39		0.14	0.11	0.10	0.10	0.05	0.03	0.04	0.06
		1973	0.33	0.35	0.35	0.27		0.10	0.09	0.11	0.07	0.04	0.06	0.10	0.05
		1974	0.42	0.41	0.40	0.37		0.10	0.13	0.10	0.08	0.05	0.06	0.12	0.06
	15-30	1973	0.10	0.09	0.19	0.05		0.07	0.06	0.10	0.06	0.03	0.02	0.04	0.01
		1974	0.12	0.12	0.08	0.11		0.10	0.16	0.07	0.07	0.02	0.01	0.06	0.02
	30-46	1971	0.09	0.09	0.09	0.10		0.19	0.28	0.28	0.17	0.01	0.02	0.01	0.02
		1973	0.12	0.10	0.11	0.18		0.16	0.18	0.58	0.21	0.02	0.02	0.02	0.02
		1974	0.11	0.14	0.14	0.15		0.17	0.19	0.21	0.15	0.02	0.02	0.03	0.01

(continued)

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TABLE 8. (continued)

Element	Depth cm	Year	Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			%												
Mg															
	South Series														
	61-76	1971	0.14	0.26	0.20	0.50	0.27**	0.18	0.13	0.15	0.13	0.01	0.01	0.02	0.02
		1973	0.46	0.71	0.23	0.52		0.20	0.23	0.29	0.14	0.02	0.03	0.01	0.02
Fe															
	North Series														
	0-15	1971	411	515	584	704		349	455	641	925	326	585	768	1047
		1972	379	622	731	794	259**	196	450	649	812	214	481	683	835
		1973	1354	1200	1695	1474		1205	1376	1487	1860	1293	1662	1395	3348
		1974	319	429	715	885	389*	336	595	555	1088	515	1125	1065	1553
	15-30	1973	794	713	746	731		576	476	669	638	353	400	536	519
		1974	471	444	430	395		309	342	408	342	212	229	502	229
	30-60	1971	833	725	736	761		850	820	527	426	247	217	319	378
		1972	523	460	515	668		552	534	568	475	237	166	150	240
		1973	1439	1594	1225	1122		1284	1940	1959	790	247	643	206	587
		1974	749	719	867	638		913	889	695	597	289	319	343	776
	61-76	1971	1376	1887	1452	1213		1171	2981	2008	1016	445	309	343	626
		1972	586	624	351	677		433	740	2087	451	138	150	126	164
		1973	875	1348	991	1297		423	851	2008	2222	711	601	751	239

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Fe															
	South Series														
	0-15	1971	498	582	514	688		654	404	395	864	281	300	640	664
		1972	246	270	438	630	219**	223	288	332	761	229	534	761	761
		1973	687	772	878	1061		633	583	659	1112	535	867	1330	1362
		1974	344	398	502	728	250**	351	448	564	1054	360	711	984	1453
	15-30	1973	755	615	577	569		455	386	413	533	400	386	329	329
		1974	320	413	421	471	100*	366	342	408	462	461	680	543	229
	30-60	1971	611	544	525	559		513	669	482	374	208	310	289	323
		1972	507	460	499	493		440	548	614	548	140	294	146	176
		1973	1251	1095	1336	1095		1363	1346	803	1314	389	446	353	525
		1974	777	731	703	776		668	786	652	726	593	652	846	652
	61-76	1971	963	1135	992	594		1360	1222	1322	1238	200	259	349	494
		1972	609	370	659			491	722	632	763	147	145	188	156
		1973	747	546	1064	364		890	294	892	1782	231	371	337	766
Mn															
	North Series														
	0-15	1971	243	292	329	377	87*	216	270	242	394	31	79	69	127
		1972	227	266	319	369	99**	187	275	297	349	52	73	70	100
		1973	561	560	742	753		547	634	586	737	138	190	109	230
		1974	352	404	478	541	119**	356	459	348	535	119	151	112	179

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Mn															
	North Series														
	15-30	1973	298	227	178	279		235	303	330	326	79	93	73	85
		1974	344	208	214	275		255	344	271	344	97	87	66	86
	30-60	1971	175	69	70	49		116	216	114	185	21	9	11	25
		1972	116	68	42	61		80	86	89	176	20	31	26	54
		1973	246	229	165	164		235	318	331	234	37	67	28	70
		1974	229	161	163	129		213	266	259	261	64	53	43	77
	61-76	1971	146	275	240	148		187	372	230	107	43	21	13	67
		1972	111	182	153	154		146	109	208	51	18	20	16	40
		1973	328	329	344	247		246	255	216	249	69	69	51	43
	South Series														
	0-15	1971	287	334	301	341		310	233	209	380	46	38	84	90
		1972	235	243	285	314		195	212	206	336	56	134	103	200
		1973	434	493	498	524		416	350	367	536	124	132	169	114
		1974	410	420	465	464		398	352	444	512	111	104	135	139
	15-30	1973	203	194	256	227		340	257	304	343	72	68	71	56
		1974	233	244	266	271		324	248	266	442	85	79	110	47

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Mn															
	South Series														
	30-60	1971	19	25	12	28		95	126	135	138	9	25	20	23
		1972	29	29	37	54		117	90	115	170	28	24	32	35
		1973	168	143	165	195		207	236	270	284	69	60	52	76
		1974	78	143	106	176	62**	140	105	196	311	70	62	88	64
	61-76	1971	102	209	143	209	82*	184	168	168	114	11	19	25	40
		1972	137	219	158	233		190	130	89	120	33	19	35	22
		1973	248	289	269	277		217	60	200	272	49	69	60	66
Zn															
	North Series														
	0-15	1971	6.0	56.6	123.9	227.0	53.6**	6.4	51.9	157.2	260.6	2.4	58.6	152.0	202.0
		1972	7.5	46.4	70.6	152.4	53.2**	11.5	59.6	88.7	169.2	4.1	37.6	81.9	126.6
		1973	19.2	68.4	109.1	248.6	107.2**	15.8	74.9	129.6	231.1	12.7	80.6	150.7	427.7
		1974	10.1	80.5	144.4	282.7	108.0**	10.4	101.6	127.7	294.3	7.6	114.1	144.8	243.1
	15-30	1973	6.9	7.3	7.4	10.7	2.8**	8.1	10.3	25.0	16.5	2.5	7.9	37.1	34.1
		1974	5.6	6.7	12.2	10.5		6.4	16.2	20.8	25.4	2.9	11.3	46.0	28.7
	30-46	1971	11.0	11.1	13.9	17.3		11.4	15.7	14.6	12.5	2.7	2.8	3.2	5.5
		1972	5.5	7.1	5.8	8.9		4.6	7.8	5.8	7.1	1.4	11.8	5.7	21.2
		1973	10.0	9.1	9.2	8.7		10.2	11.8	14.5	7.0	2.0	4.0	2.9	10.2
		1974	5.4	4.7	7.8	6.5		5.6	11.4	15.5	19.4	1.8	2.1	5.4	9.1

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Zn															
	South Series														
	61-76	1971	14.0	17.3	21.2	22.5		10.1	30.0	7.7	24.9	3.8	2.9	5.8	12.7
		1972	6.3	8.1	6.8	11.4	3.3**	5.6	7.8	0.5	8.0	2.0	5.5	3.8	15.1
		1973	8.2	12.1	11.7	11.3		6.3	8.0	0.9	13.7	3.3	3.5	5.3	4.8
Z															
	South Series														
	0-15	1971	6.0	19.8	62.3	140.9	12.7**	6.3	23.7	57.5	150.9	1.6	17.6	62.0	113.4
		1972	4.8	28.8	49.9	104.5	61.8**	4.6	28.5	48.9	148.5	3.7	44.6	84.7	102.3
		1973	14.6	47.4	91.6	145.7	28.1**	16.3	39.4	79.8	117.0	8.1	98.6	142.8	158.6
		1974	8.8	51.9	100.0	188.2	33.7**	9.0	45.7	91.7	232.3	7.7	65.6	147.2	197.9
	15-30	1973	5.7	6.0	8.4	9.5		8.2	8.0	20.6	18.2	2.8	8.4	14.7	12.5
		1974	6.2	7.2	6.4	20.4		5.5	6.2	13.1	48.9	3.1	8.9	28.8	21.3
	30-60	1971	7.0	8.5	8.5	12.2		7.5	9.6	19.4	15.5	2.8	18.5	20.2	23.2
		1972	5.1	5.8	8.4	9.5		6.2	11.7	12.5	29.2	3.9	4.6	7.9	14.8
		1973	7.8	7.1	8.1	9.3		7.8	9.3	8.3	16.8	2.3	2.5	2.9	5.0
		1974	7.0	7.1	6.4	8.8		7.0	6.7	14.6	27.0	6.0	3.4	5.7	8.0
	61-76	1971	12.6	14.6	14.6	12.1		15.2	15.4	20.0	25.0	2.2	12.3	19.8	26.7
		1972	9.1	8.6	10.5	3.9		8.5	11.8	9.3	14.8	5.3	2.4	4.5	5.9
		1973	5.3	5.6	10.2	4.9	3.9*	6.2	2.0	6.4	12.0	1.6	1.4	1.6	5.7

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			Soil type												
Cd			ppm												
	North Series														
	0-15	1971	0.6	3.5	6.8	12.6	3.1**	0.4	3.0	8.6	14.9	0.2	3.5	7.7	11.0
		1972	<0.1	2.0	3.8	8.0	1.2**	<0.1	2.6	4.4	9.1	<0.1	1.4	3.3	5.6
		1973	0.4	3.6	6.5	13.1	6.6**	0.1	3.1	6.4	11.9	0.3	3.6	7.1	20.1
		1974	0.2	3.8	7.8	15.3	4.4**	0.2	4.8	7.1	16.0	<0.1	4.7	7.3	13.4
	15-30	1973	0.2	0.2	0.1	0.4		0.1	0.4	1.0	0.7	<0.1	0.3	0.5	1.5
		1974	<0.1	0.2	0.2	0.1		<0.1	0.3	0.5	0.9	<0.1	0.2	3.2	1.5
	30-46	1971	0.3	0.5	0.7	0.6		0.5	0.8	0.9	0.7	<0.1	0.1	<0.1	0.3
		1972	<0.1	<0.1	<0.1	0.1		<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	0.1
		1973	<0.1	<0.1	<0.1	0.1		0.1	0.1	<0.1	0.1	<0.1	<0.1	0.1	0.3
		1974	<0.1	<0.1	<0.1	0.2		<0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	0.1
	61-76	1971	0.3	0.6	0.6	0.6		1.4	1.9	1.3	4.5	<0.1	0.1	0.5	0.3
		1972	<0.1	<0.1	<0.1	<0.1		<0.1	0.2	0.2	0.2	<0.1	<0.1	<0.1	<0.1
		1973	0.2	0.2	0.3	0.3		0.2	0.2	0.4	0.2	0.1	0.3	0.2	0.3
	South Series														
	0-15	1971	0.7	2.4	3.9	7.4	1.7**	0.4	1.8	3.5	8.1	0.2	1.2	3.7	6.0
		1972	0.1	1.4	2.6	5.7	3.2**	<0.1	1.5	2.6	7.5	<0.1	2.2	4.5	5.1
		1973	0.3	2.3	4.4	9.9	2.7**	0.3	1.5	3.3	5.9	0.2	4.2	8.4	10.1
		1974	0.2	2.9	5.2	10.7	1.3**	<0.1	2.5	4.8	11.3	<0.1	3.3	6.4	9.8

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Blount silt loam Ck	Blount silt loam 1/4 Max	Blount silt loam 1/2 Max	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4 Max	Elliott silt loam 1/2 Max	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4 Max	Plainfield loamy sand 1/2 Max	Plainfield loamy sand Max
			ppm												
Cd															
	South Series														
	15-30	1973	<0.1	0.3	0.1	0.3		0.1	0.1	0.2	0.5	<0.1	0.1	0.5	0.4
		1974	<0.1	<0.1	<0.1	0.6		<0.1	<0.1	0.5	2.0	<0.1	<0.1	1.3	0.9
	30-46	1971	0.1	0.1	0.2	0.3		0.3	0.3	1.0	0.7	<0.1	0.8	0.7	0.8
		1972	<0.1	<0.1	<0.1	0.1		<0.1	0.3	0.3	1.3	<0.1	<0.1	<0.1	0.4
		1973	<0.1	<0.1	<0.1	0.2		<0.1	0.1	0.2	0.7	<0.1	<0.1	<0.1	<0.1
		1974	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1	0.4	0.9	<0.1	<0.1	<0.1	<0.1
	61-76	1971	0.2	0.4	0.5	0.9		0.4	0.4	0.5	1.1	0.8	0.9	1.3	1.2
		1972	<0.1	0.2	0.1	0.3		0.1	0.1	<0.1	0.4	<0.1	<0.1	<0.1	<0.1
		1973	0.2	0.3	0.2	0.5		0.2	<0.1	<0.1	0.4	<0.1	0.2	0.1	0.1
Cu															
	North Series														
	0-15	1971	2.6	15.8	31.9	54.4	17.6**	3.0	15.2	41.4	73.2	1.2	20.6	44.4	49.7
		1972	4.5	13.0	21.9	43.9	4.3**	7.1	15.3	22.4	44.5	6.0	9.4	28.8	35.2
		1973	8.4	17.0	28.1	58.2	27.5**	6.2	18.2	30.9	55.8	5.7	18.0	34.5	90.1
		1974	5.5	21.1	37.2	71.6	26.7**	4.8	23.3	32.4	65.8	3.0	22.9	37.2	59.4
	15-30	1973	4.1	3.6	4.2	4.7		3.4	3.7	8.0	5.8	1.3	2.6	12.8	9.9
		1974	3.0	3.4	4.6	3.9		3.2	5.0	5.5	6.6	1.2	3.4	11.4	8.5
	30-46	1971	4.0	4.9	5.1	6.2		3.7	4.4	5.4	3.9	1.1	1.3	0.7	1.4
		1972	4.4	8.7	4.2	4.6		4.0	6.7	4.8	5.2	2.2	5.7	4.3	8.8
		1973	4.7	5.6	4.9	5.1		4.5	5.7	5.6	4.0	1.5	1.6	4.2	3.0
		1974	3.4	3.5	4.3	3.8		3.3	4.8	6.2	4.2	1.5	1.3	2.6	2.6

(continued)

TABLE 8. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Element	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cu															
	North Series														
	61-76	1971	4.6	4.2	5.2	6.9	1.5*	5.4	9.6	0.2	8.6	0.9	1.0	1.7	2.9
		1972	4.0	4.6	2.8	4.8		1.8	5.4	<0.2	6.2	1.7	0.2	4.3	4.9
		1973	6.5	4.3	5.3	6.8		3.2	4.7	<0.2	5.4	2.6	1.4	2.2	10.9
Cu															
	South Series														
	0-15	1971	3.0	8.0	16.8	35.0	4.1**	3.6	10.6	18.0	41.2	1.0	8.1	22.4	37.3
		1972	4.4	10.1	14.8	31.0	16.8**	4.1	8.8	14.8	39.9	6.4	17.2	24.5	27.5
		1973	5.4	13.8	23.0	42.2	10.4**	4.2	10.2	29.8	31.6	3.2	23.0	39.9	49.6
		1974	2.9	13.4	23.0	44.7	5.4**	2.6	12.4	21.5	49.0	1.6	15.7	30.2	43.5
	15-30	1973	5.8	7.0	4.9	5.3		3.3	3.8	4.8	7.8	2.0	3.3	6.9	4.6
		1974	2.8	3.5	3.8	8.3		3.4	3.7	5.2	11.4	1.3	2.6	7.6	7.0
	30-46	1971	3.6	4.1	4.0	4.9		3.8	3.7	5.8	4.9	0.9	4.9	5.5	5.9
		1972	3.9	4.2	5.6	5.3		4.0	6.7	6.0	9.5	3.5	3.5	6.5	4.5
		1973	4.6	3.9	4.8	5.2		4.3	5.7	3.8	8.8	3.5	2.3	1.8	1.7
		1974	7.0	3.8	4.4	4.7		2.8	4.5	6.6	7.8	2.2	1.4	1.7	3.8
	61-76	1971	5.2	4.2	4.8	3.3		4.3	4.6	7.0	7.6	0.9	3.4	5.1	6.7
		1972	5.3	4.1	5.4	7.0		4.5	4.9	5.7	6.7	4.6	2.7	5.6	4.0
		1973	4.5	4.3	5.7	3.1		4.7	2.0	4.4	7.2	3.8	1.1	2.4	4.6

(continued)

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TABLE 8. (continued)

			Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Element	Depth cm	Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Ni															
	North Series														
	0-15	1971	3.1	3.9	6.6	10.5	3.7**	2.5	5.5	7.0	9.7	<1.0	1.9	4.7	10.2
		1972	3.8	4.7	5.9	9.6	3.6**	2.6	8.2	6.7	9.2	<1.0	<1.0	3.3	5.2
		1973	5.6	7.3	9.2	15.2	6.8**	5.8	6.2	8.9	14.5	2.4	4.3	5.8	14.8
		1974	3.5	5.8	8.0	11.7	5.7**	3.4	6.7	6.1	6.7	<1.0	3.5	4.8	8.4
	15-30	1973	2.6	3.4	1.9	3.0		3.1	4.0	4.6	4.8	3.0	4.6	5.1	4.4
		1974	1.9	2.1	1.0	2.0		2.9	3.2	2.9	3.2	<1.0	<1.0	1.0	<1.0
	30-46	1971	2.7	2.3	2.2	2.4		2.8	3.7	3.5	3.6	<1.0	<1.0	<1.0	<1.0
		1972	4.7	3.9	4.5	3.6		4.5	2.0	5.0	5.0	1.4	<1.0	1.7	1.7
		1973	3.3	3.0	2.0	2.7		3.0	3.6	5.3	3.2	<1.0	1.2	<1.0	1.6
		1974	1.0	1.5	2.0	1.3		2.6	2.9	2.7	3.7	<1.0	<1.0	1.1	1.3
	61-76	1971	3.4	9.2	7.8	6.9		4.0	9.4	4.6	5.2	1.1	<1.0	<1.0	<1.0
		1972	3.0	7.3	6.6	5.7		5.5	1.8	7.1	2.9	1.3	4.9	3.6	3.6
		1973	2.9	8.8	6.8	5.0		2.8	4.6	4.2	2.5	1.5	<1.0	<1.0	<1.0
Ni															
	South Series														
	0-15	1971	3.3	5.0	5.4	8.0	1.8**	3.7	4.1	5.2	8.6	<1.0	1.6	4.6	5.3
		1972	6.7	7.0	9.0	9.4	2.7**	5.1	4.0	7.2	13.8	3.5	4.6	6.1	5.6
		1973	4.0	5.1	7.7	7.7		3.3	4.4	4.8	8.0	9.4	5.7	8.0	7.0
		1974	3.6	5.4	6.4	9.0	3.4**	3.9	5.2	6.3	11.0	1.3	3.2	4.2	6.9

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type Blount silt loam Ck	1/4 Max	1/2 Max	Max	LSD	Elliott silt loam Ck	1/4 Max	1/2 Max	Max	Plainfield loamy sand Ck	1/4 Max	1/2 Max	Max
			ppm												
Ni															
	South Series														
	15-30	1973	1.8	2.0	2.4	2.1		3.2	2.7	3.3	3.3	2.7	2.1	3.1	3.1
		1974	1.4	1.0	1.2	1.5		2.0	0.5	2.3	4.0	<1.0	<1.0	1.5	0.5
	30-46	1971	1.4	1.8	1.7	2.3		2.1	2.7	2.7	3.6	<1.0	1.5	1.4	1.3
		1972	1.4	2.9	1.2	2.9		3.0	2.7	2.7	3.8	<1.0	2.7	3.2	1.7
		1973	2.0	1.9	1.9	3.2		2.5	2.8	5.2	4.3	<1.0	1.0	<1.0	1.4
		1974	1.1	1.2	1.8	2.2		1.2	2.7	2.7	3.8	1.3	1.2	1.5	2.2
	61-76	1971	5.6	9.8	7.1	6.0		3.3	8.1	7.1	4.0	<1.0	<1.0	<1.0	1.0
		1972	5.6	7.4	5.4	6.9		6.6	9.1	3.6	3.6	1.8	1.0	1.5	0.5
		1973	7.3	10.3	10.2	8.9		7.0		3.8	7.9	1.1	1.5	0.9	3.3
Cr															
	North Series														
	0-15	1971	2.5	7.5	17.6	29.8	18.0*	0.6	6.9	23.3	51.2	0.4	16.4	43.7	56.5
		1972	0.4	5.1	10.1	18.6	4.7**	1.5	6.7	9.3	19.4	0.3	6.4	16.0	22.9
		1973	3.6	13.1	25.8	55.7	29.4*	2.5	12.2	24.0	51.4	3.9	21.4	45.5	89.2
		1974	1.3	10.3	10.1	45.0	25.6**	0.5	11.7	20.6	50.3	1.1	22.3	36.4	56.8
	15-30	1973	0.4	0.8	0.6	1.1		0.5	1.0	2.3	1.7	<0.2	1.0	8.0	5.1
		1974	1.1	1.3	1.4	1.1		0.7	0.7	0.7	1.3	1.0	5.2	9.4	5.2

(continued)

TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cr															
	North Series														
	30-46	1971	0.8	1.0	1.0	1.1		1.3	1.3	0.6	0.6	0.4	<0.2	0.4	0.9
		1972	0.2	0.2	<0.2	0.3		0.4	0.3	0.3	0.5	<0.2	0.2	0.4	1.4
		1973	2.5	2.1	2.1	2.4		2.5	2.5	2.8	2.1	0.7	1.8	1.1	2.5
		1974	<0.2	<0.2	0.8	0.3		0.6	0.4	1.2	0.4	<0.2	<0.2	0.4	0.4
	61-76	1971	1.5	1.8	2.1	2.0		1.1	2.8	2.9	2.4	0.5	0.3	0.9	2.4
		1972	0.4	0.5	0.5	0.5		0.4	0.2	<0.2	0.5	0.6	0.9	0.9	0.9
		1973	3.1	2.8	2.6	2.6		2.5	2.6	1.6	3.3	1.3	0.2	2.3	1.6
Cr															
	South Series														
	0-15	1971	0.9	2.7	7.9	23.0	4.0**	0.8	3.2	8.6	33.7	0.4	3.9	20.1	31.0
		1972	3.0	2.3	3.6	9.1	5.0*	1.6	4.1	6.9	18.6	0.3	7.8	17.2	17.2
		1973	0.8	5.6	13.1	28.4	8.7**	0.4	2.2	8.8	22.4	1.1	19.3	45.7	56.8
		1974	0.7	5.7	12.2	24.4	8.1**	0.7	5.9	12.4	33.4	1.1	12.8	29.4	50.4
	15-30	1973	1.8	1.4	1.7	1.8		0.7	1.7	2.0	2.0	0.9	2.7	3.8	2.4
		1974	0.4	1.4	1.3	3.4		0.3	0.7	2.0	4.1	1.0	2.3	6.4	2.3
	30-46	1971	0.7	0.6	0.7	0.9		0.7	0.8	1.5	1.1	1.0	3.3	3.2	4.4
		1972	0.6	0.5	0.7	0.9		0.6	0.7	1.6	3.0	0.6	0.3	0.6	1.3
		1973	2.3	2.2	2.6	2.2		2.1	2.6	3.4	4.8	1.2	1.2	1.6	2.3
		1974	0.7	1.1	0.5	1.2		1.0	0.4	2.6	3.4	0.4	0.8	1.2	0.8

(continued)

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TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Cr															
	South Series														
	61-76	1971	0.8	1.1	1.1	0.9		1.0	1.1	1.6	2.2	0.2	1.7	2.7	4.8
		1972	0.6	0.9	0.9	0.5		0.7	1.2	0.6	1.8	0.4	0.6	0.2	0.2
		1973	2.1	2.4	0.8	1.9		1.9	1.7	2.1	2.1	2.4	2.8	0.4	1.7
Pb															
	North Series														
	0-15	1971	5.5	13.6	22.5	31.5	18.9**	5.2	11.5	28.2	51.4	3.5	17.4	31.0	41.9
		1972	4.2	11.0	16.2	32.2	7.0**	3.3	11.7	16.6	36.9	1.1	7.3	16.0	23.2
		1973	10.2	18.1	27.4	51.9	26.2**	7.1	19.1	30.2	46.4	3.2	17.4	33.2	90.3
		1974	7.2	21.6	36.7	60.5	23.7**	6.2	23.7	27.2	59.8	3.7	28.0	34.2	58.8
	15-30	1973	7.4	7.8	7.6	6.1		6.1	5.6	8.4	8.9	1.6	5.0	10.6	7.8
		1974	5.9	6.4	7.1	4.5		5.9	<1.0	8.0	7.5	1.8	3.8	12.7	8.5
	30-46	1971	6.8	7.1	6.1	5.1		5.8	6.4	5.4	4.7	1.1	1.9	2.5	2.2
		1972	4.2	3.7	3.8	3.7		3.8	3.1	3.1	3.5	<1.0	1.0	<1.0	1.6
		1973	6.2	4.2	5.8	6.4		6.9	9.1	5.8	3.7	<1.0	1.6	<1.0	1.6
		1974	5.8	7.6	7.4	6.0		5.9	6.3	11.0	7.1	2.4	1.4	2.1	2.9
	61-76	1971	5.8	7.3	7.7	7.6		4.4	6.6	3.2	7.3	2.6	1.6	1.3	3.9
		1972	3.2	5.9	3.8	3.8		3.0	4.2	1.4	4.7	<1.0	<1.0	<1.0	1.4
		1973	7.7	10.5	8.2	8.1		6.0	7.1	1.8	9.9	1.8	3.3	7.1	1.3

(continued)

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TABLE 8. (continued)

Element	Depth cm	Year	Soil type												
			Blount silt loam					Elliott silt loam				Plainfield loamy sand			
			Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
			ppm												
Pb															
	South Series														
	0-15	1971	6.0	8.7	15.2	25.5	1.6**	5.7	9.7	13.0	30.9	2.7	6.1	17.1	22.8
		1972	4.4	7.7	11.7	23.6	11.3*	3.9	6.8	9.9	36.9	1.9	9.9	17.2	15.5
		1973	7.6	17.5	26.0	33.9	14.7**	6.7	14.0	16.3	29.9	2.8	14.6	38.5	45.5
		1974	7.8	17.2	27.2	44.3	7.0**	7.1	14.3	22.9	48.1	4.2	16.0	35.0	46.4
	15-30	1973	5.6	4.9	5.5	5.8		6.4	4.6	6.2	6.7	2.1	3.5	3.5	3.5
		1974	7.6	6.9	4.8	10.4		3.8	5.9	6.4	13.7	2.2	3.8	6.4	5.9
	30-46	1971	3.3	5.2	3.8	6.2	1.9*	4.7	5.4	6.7	6.7	1.5	4.2	4.6	3.6
		1972	3.3	3.9	4.1	3.8		4.0	5.2	6.7	7.7	1.0	2.4	<1.0	1.9
		1973	6.5	8.4	7.1	8.8		5.9	8.9	9.5	11.2	1.2	<1.0	6.2	2.9
		1974	6.4	6.4	5.5	6.5		6.3	5.6	9.5	9.0	6.5	1.9	1.9	3.6
	61-76	1971	8.2	6.3	6.7	6.6		6.4	8.7	8.7	7.8	1.9	3.9	5.5	7.4
		1972	3.6	4.6	4.4	2.9		4.0	3.3	4.8	5.2	<1.0	<1.0	<1.0	3.2
		1973	5.7	5.5	6.1	6.1		3.3	<1.0	6.5	5.9	4.9	<1.0	<1.0	4.8

a/ Concentrations are reported as ppm dry weight of soil from samples collected each spring from plots in a north and south series.

b/ Control plots were annually treated with inorganic fertilizer to compare with three different loading rates of digested sludge.

*,** Significant at P<0.05 and P<0.01, respectively.

Corn Grain and Stover Yields

The most outstanding feature of the data presented in Table 9 is the significant increase in grain yields observed on Blount silt loam plots in the north series during the last 3 years of the study. Prior to 1974 grain yields were not affected by annual sludge applications. But yields were increased during the 2nd, 3rd, and 4th years after termination of sludge treatments. Blount silt loam plots in the south series produced less corn grain in 1971 and 1974 where ¼- and ½-maximum-sludge-treatments were made as compared to yields from irrigated control plots. On the other hand yields from Blount silt loam maximum-sludge-treated plots were not significantly different from those produced on control plots, except in 1975, in the south series. For this one year grain yields were less on maximum-sludge-treated plots ($P \leq 0.05$) than those obtained from irrigated control plots. But stover yields from the same maximum-sludge-treated plots were the highest ever produced during the study, regardless of treatment. It is noteworthy, that the lowest grain yields on Elliott silt loam soils treated with maximum rates of sludge occurred during years when stover yields were highest. Stover yields on ¼-maximum-sludge-treated plots, in both the north and south series, were frequently lower than those on either the control or maximum-sludge-treated plots. Because of the exceedingly low capacity to store available moisture, yields of both grain and stover on Plainfield loamy sand were generally lower than those produced on the other two soil types. Even though organic-C contents in Plainfield loamy sand were increased by sludge applications there is no evidence that the available water holding capacity was sufficiently increased to furnish moisture supplies required for the production of high yields.

Grain and stover yields from Blount silt loam plots in the south series were not reported for 1976 and 1977 because these plots were devoted to a screening study to identify corn inbreds that exclude the uptake of some metals to low levels. These results are discussed as a special separate study.

Changes in Inorganic Chemical Concentrations in Plant Tissues

For several years after the study was initiated plant tissues were ashed in a muffle furnace preparatory to analyzing them for concentrations of the several elements reported here. This practice was abandoned in favor of wet digestion because of the possibility that a portion of some elements might have been volatilized during ashing. All samples were later reanalyzed using wet digestion techniques, but during the time ashing by combustion was used the percent ash of corn leaves, grain and stover was recorded and the results are presented in Table 10. Only leaves from Blount silt loam plots in the north series were significantly higher in ash contents, but ash contents in all leaf and stover samples from all soil types and locations showed a consistent trend toward higher values with high sludge loading rates.

Maximum sludge treatments caused significantly higher N levels in leaves from Bount silt loam in the north series only in 1971. On the other hand N concentrations in grain were generally higher in grain from maximum-sludge-treated plots for all soil types. Sludge treatments affected N

(continued on Page 255)

TABLE 9. CORN GRAIN AND STOVER YIELDS FROM LYSIMETER PLOTS OF THREE SOIL TYPES, WITH AND WITHOUT SEWAGE SLUDGE IRRIGATIONS. ALL THREE SOIL TYPES WERE REPRESENTED IN A NORTH AND SOUTH SERIES.

	Soil type												
	Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
North Series													
	-----------------------------Grain mt/ha (15.5% moist)------------------------												
71	4.85	6.06	6.44	5.98	n.s.	4.24	6.64	3.86	3.58	-	1.46	-	-
72	6.38	7.21	8.27	7.48	n.s.	6.70	8.21	8.53	6.97	5.07	5.88	6.31	7.06
73	6.32	5.24	6.94	6.98	n.s.	7.18	6.54	5.87	6.36	2.90	1.22	0.20	2.52
74	2.50	3.39	3.39	3.04	n.s.	5.00	4.08	3.98	3.88	0.83	0.36	1.69	2.55
75	6.35	6.91	7.65	9.05	1.71*	8.45	8.27	7.66	8.66	0.75	0.63	2.51	4.38
76	4.57	5.96	7.92	8.49	1.77**	8.57	7.25	7.23	9.11	0.63	1.19	1.57	3.24
77	4.74	4.92	6.55	6.86	1.52**	6.59	6.25	6.71	1.95	0.56	1.21	1.98	1.51
	--------------------------------Stover mt/ha (Dry Wt.)-------------------------												
72	5.98	6.51	6.55	6.06	n.s.	4.99	5.57	6.08	4.69	5.44	6.02	5.62	6.00
73	6.72	3.93	4.88	5.13	1.39*	5.24	3.81	4.05	5.85	3.27	2.64	3.07	2.40
74	5.13	3.05	5.17	5.87	1.48*	4.82	4.95	4.37	13.60	3.85	2.80	5.76	6.61
75	5.60	6.12	6.29	9.09	n.s.	8.00	5.91	6.34	9.07	1.39	1.34	2.35	5.49
76	4.01	4.69	5.17	5.79	n.s.	6.03	4.88	5.15	4.95	1.35	1.61	1.90	2.39
77	6.66	6.09	8.36	8.59	2.12**	8.39	4.78	6.97	10.82	1.88	2.32	2.92	4.66

(continued)

TABLE 9. (continued)

	Soil type												
	Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Year	Ck	1/4 Max	1/2 Max	Max	LSD	Ck	1/4 Max	1/2 Max	Max	Ck	1/4 Max	1/2 Max	Max
South Series													
	Grain mt/ha (15.5% moist)												
71	5.90	3.00	4.26	5.23	1.23**	7.50	3.53	6.32	7.31	3.15	0.41	-	0.12
72	6.30	6.62	6.45	5.88	n.s.	6.87	8.13	7.85	8.30	5.93	4.79	3.90	5.62
73	6.70	4.45	3.99	5.22	n.s.	7.29	4.07	4.59	5.36	3.62	0.23	0.14	0.31
74	4.03	1.97	1.74	3.99	1.69**	5.22	2.10	3.58	4.32	2.28	0.58	1.34	2.27
75	9.18	7.88	8.22	8.25	0.84*	9.58	8.30	8.90	9.06	5.68	1.34	2.74	2.41
76	-	-	-	-		8.54	8.14	7.95	7.43	2.72	1.50	1.43	2.65
77	-	-	-	-		6.86	5.14	3.08	4.05	0.77	1.07	0.89	0.51
	Stover mt/ha (Dry Wt.)												
72	5.17	5.87	5.82	5.75	n.s.	5.10	5.86	5.83	4.97	5.40	6.93	5.63	5.78
73	5.58	3.83	4.75	5.53	0.94**	4.05	4.66	6.45	5.76	3.85	3.23	3.18	4.35
74	7.13	6.41	10.99	8.31	n.s.	1.16	13.07	9.70	13.84	4.66	6.46	6.62	10.07
75	8.11	6.76	8.85	9.52	1.66*	8.15	8.69	10.06	8.71	2.96	3.76	4.21	5.31
76	-	-	-	-		6.78	6.38	6.48	9.18	3.12	2.44	2.71	3.00
77	-	-	-	-		8.56	11.06	12.42	10.36	2.79	3.86	6.37	5.07

*, ** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 10. CONCENTRATIONS OF ASH AND MACRO- AND MINOR-ELEMENTS IN CORN LEAF, GRAIN, AND STOVER GROWN ON BLOUNT SILT LOAM, ELLIOTT SILT LOAM, AND PLAINFIELD LOAMY SAND LYSIMETER PLOTS, WITH AND WITHOUT DIGESTED SLUDGE IRRIGATIONS.a/b/

		Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Constituent	Year	Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
North Series														
		Leaf %												
Ash	1971	6.29	6.08	6.64	6.98	.43**	6.58	6.36	6.82	7.78	6.81	7.00	7.42	8.45
	1972	6.73	7.52	7.80	8.32	.97**	7.28	9.26	8.60	9.74	5.98	6.46	7.71	8.81
	1973	7.95	8.50	8.40	9.11		9.20	7.74	9.89	10.54	6.89	7.95	7.76	9.02
		Grain %												
	1971	1.30	1.24	1.11	1.18		1.24	1.15	1.15	1.56		1.34		
	1972	1.32	1.40	1.40	1.41		1.64	1.28	1.42	1.34	1.61	1.30	1.59	1.47
	1973	1.33	1.39	1.34	1.46		1.55	1.28	1.31	1.39	1.56	1.44	1.44	1.45
	1974	1.51	1.37	1.38	1.40		1.42	1.34	1.51	1.43	1.66	1.57	1.48	1.86
	1975	1.58	1.51	1.48	1.44		1.57	1.34	1.64	1.39	1.78	1.74	1.80	1.62
		Stover %												
	1972	5.68	5.67	5.96	6.39		5.51	6.98	5.72	8.17	6.73	5.98	6.68	8.04
	1973	5.17	4.19	4.62	5.03		4.16	4.35	3.74	5.65	5.08	6.14	4.24	8.22

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	1/4	1/2	Max	LSD	Elliott silt loam Ck	1/4	1/2	Max	Plainfield loamy sand Ck	1/4	1/2	Max
South Series														
							Leaf							
							%							
	1971	6.31	5.97	6.29	6.36		6.89	6.15	6.84	7.49	6.12	5.98	6.29	6.30
	1972	6.89	6.71	6.72	6.92		7.00	7.30	7.42	8.49	6.42	6.19	6.66	7.31
	1973	8.75	8.06	8.67	9.33		9.06	9.64	10.56	11.52	7.44	7.67	8.76	9.03
							Grain							
							%							
	1971	1.13	1.12	1.19	1.17		1.22	1.35	1.01	1.26	1.36	1.25		1.74
	1972	1.37	1.27	1.40	1.38		1.34	1.43	1.34	1.59	1.60	1.36	1.35	1.44
	1973	1.41	1.32	1.38	1.28		1.36	1.50	1.34	1.33	1.52	1.63	1.30	1.29
	1974	1.37	1.53	1.48	1.58		1.34	1.57	1.57	1.45	1.56	1.85	1.59	1.47
	1975	1.50	1.48	1.55	1.70		1.63	1.54	1.72	1.78	1.71	1.67	1.64	1.72
							Stover							
							%							
	1972	5.53	4.99	5.11	6.23		5.42	5.55	5.78	6.94	6.76	6.79	6.58	8.10
	1973	4.09	4.81	4.68	5.29		4.28	4.34	4.77	5.88	4.76	5.38	7.05	6.82

(continued)

TABLE 10. (continued)

Constituent	Year	Soil type Blount silt loam Ck	1/4	1/2	Max	LSD	Elliott silt loam Ck	1/4	1/2	Max	Plainfield loamy sand Ck	1/4	1/2	Max
North Series														
		Leaf %												
N	1971	2.80	2.94	3.10	3.23	.31**	2.60	3.22	3.00	3.02	2.63	2.78	3.02	3.14
	1972	3.21	2.66	3.24	4.82		2.31	1.54	3.35	3.30	2.66	2.74	2.88	2.83
	1973	2.77	2.79	2.86	3.00		2.85	2.91	2.78	2.97	2.74	2.67	2.84	3.10
	1974	2.88	2.57	2.65	2.94		3.09	2.84	2.64	2.76	3.10	2.02	2.85	3.39
	1975	1.87	2.03	2.12	2.80		3.35	2.45	2.38	3.24	1.22	1.26	2.55	3.05
	1976	2.67	2.16	2.14	2.43		2.77	2.00	2.09	2.56	1.42	1.85	2.04	2.70
	1977	2.75	2.31	2.62	2.74	.27*	2.61	2.32	2.33	3.01	1.68	1.64	2.08	2.63
		Grain %												
	1971	1.88	1.82	1.95	1.94		1.85	1.93	2.26	2.16		1.98		
	1972	1.51	1.59	1.70	1.78	.13**	1.52	1.56	1.77	1.74	1.71	1.74	1.90	1.85
	1973	1.44	1.57	1.64	1.71	.19**	1.52	1.67	1.86	1.86	1.77	1.86	2.18	1.94
	1974	1.58	1.45	1.59	1.90	.30**	1.42	1.46	1.85	1.30	1.90	1.75	1.52	1.81
	1975	1.32	1.35	1.44	1.49		1.50	1.26	1.46	1.58	0.99	1.14	1.42	1.75
	1976	1.18	1.20	1.23	1.32		1.49	1.06	1.19	1.62	1.10	1.15	1.52	2.02
	1977	1.49	1.46	1.46	1.60		1.63	1.24	1.37	1.82	1.26	1.24	1.80	2.00
		Stover %												
	1972	0.82	1.10	0.96	1.14		0.80	0.99	0.92	1.11	0.97	0.93	1.23	1.36
	1973	1.18	1.00	0.80	1.17		0.70	0.66	1.28	1.53	1.15	0.98	0.83	1.66
	1974	1.03	0.76	0.76	1.21	.33*	0.98	0.59	1.34	1.91	1.61	1.17	1.26	2.05
	1975	0.40	0.38	0.44	0.47		0.82	0.37	0.39	0.80	0.60	0.41	0.36	1.55
	1976	0.42	0.34	0.34	0.42		0.68	0.35	0.41	1.03	0.42	0.35	0.52	1.57
	1977	0.60	0.63	0.64	0.83		0.76	0.59	0.74	1.68	0.68	0.78	0.84	1.71

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		%												
N	1971	3.11	2.91	3.03	2.95	.12*	3.23	3.06	3.27	3.20	3.35	3.10	3.33	3.53
	1972	2.92	2.95	2.88	3.00		2.82	2.37	2.16	2.94	2.91	2.96	2.22	3.07
	1973	2.82	2.72	2.85	2.88		2.72	2.62	2.85	2.79	2.88	2.50	2.82	2.90
	1974	2.95	2.74	2.91	3.10		2.99	2.64	2.80	2.94	2.88	2.71	2.88	3.31
	1975	3.09	3.00	3.00	3.08		3.09	3.23	3.34	3.37	2.03	2.25	2.93	3.06
	1976						2.65	2.27	2.77	2.82	2.75	2.29	2.67	2.58
	1977						2.63	2.72	2.94	2.86	1.66	2.61	2.60	3.08
		Grain												
		%												
	1971	1.72	1.89	1.75	2.07	.23*	1.66	1.88	1.94	2.04	1.82	1.85		2.60
	1972	1.48	1.52	1.71	1.76	.14**	1.45	1.50	1.66	1.64	1.63	1.89	1.89	1.86
	1973	1.54	1.62	1.82	1.93	.21**	1.50	1.76	1.79	1.86	1.90	1.99	1.90	2.18
	1974	1.38	1.63	1.65	1.61	.15*	1.39	1.66	1.64	1.69	1.47	1.62	1.80	1.89
	1975	1.49	1.56	1.59	1.78	.18*	1.37	1.60	2.11	1.74	1.50	1.91	1.83	2.00
	1976						1.47	1.44	1.59	1.72	1.83	1.83	2.15	1.98
	1977						1.62	1.98	2.09	1.90	1.48	1.87	2.06	2.37
		Stover												
		%												
	1972	0.64	1.00	0.83	0.82	.23**	0.63	0.85	0.96	1.06	0.90	0.99	1.58	1.18
	1973	0.76	1.19	1.24	1.28		0.94	0.91	1.31	1.32	1.36	1.96	2.36	2.65
	1974	1.00	1.15	1.16	1.18		1.01	1.07	0.89	0.82	0.80	1.57	1.63	1.44
	1975	0.62	0.77	0.80	1.00		0.58	0.80	0.76	0.96	0.69	1.36	1.50	1.43
	1976						0.81	0.81	1.18	1.39	1.44	2.09	2.01	1.69
	1977						0.65	1.63	1.82	1.82	0.96	1.33	2.03	2.25

(continued)

TABLE 10. (continued)

		Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Constit-uent	Year	Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
North Series														
		Leaf												
		%												
P	1971	0.31	0.30	0.30	0.30		0.31	0.32	0.27	0.33	0.50	0.36	0.35	0.39
	1972	0.37	0.33	0.37	0.40	.05*	0.38	0.34	0.36	0.44	0.41	0.33	0.35	0.48
	1973	0.33	0.33	0.32	0.35		0.33	0.31	0.35	0.39	0.42	0.32	0.38	0.43
	1974	0.47	0.42	0.41	0.40		0.46	0.45	0.43	0.43	0.50	0.43	0.50	0.53
	1975	0.27	0.24	0.28	0.24		0.31	0.21	0.23	0.36	0.40	0.38	0.26	0.33
	1976	0.40	0.31	0.29	0.31		0.35	0.29	0.32	0.38	0.54	0.52	0.57	0.41
	1977	0.28	0.26	0.24	0.26		0.25	0.26	0.26	0.32	0.40	0.34	0.30	0.41
		Grain												
		%												
	1971	0.34	0.31	0.29	0.30	.03*	0.35	0.34	0.34	0.38		0.37		
	1972	0.30	0.33	0.33	0.33		0.35	0.26	0.33	0.32	0.37	0.32	0.40	0.35
	1973	0.30	0.29	0.30	0.33		0.29	0.30	0.31	0.34	0.35	0.35	0.34	0.34
	1974	0.33	0.31	0.31	0.32		0.31	0.29	0.34	0.35	0.38	0.38	0.33	0.40
	1975	0.31	0.30	0.29	0.29		0.35	0.29	0.32	0.47	0.46	0.46	0.45	0.37
	1976	0.36	0.32	0.32	0.32		0.34	0.35	0.33	0.40	0.41	0.39	0.39	0.42
	1977	0.34	0.32	0.31	0.32		0.40	0.36	0.35	0.34	0.40	0.35	0.34	0.36
		Stover												
		%												
	1972	0.07	0.11	0.10	0.14		0.08	0.13	0.09	0.20	0.30	0.10	0.20	0.34
	1973	0.14	0.14	0.11	0.19		0.09	0.20	0.17	0.23	0.25	0.17	0.31	0.30
	1974	0.10	0.08	0.06	0.11		0.06	0.04	0.11	0.22	0.21	0.23	0.15	0.27
	1975	0.06	0.06	0.05	0.04		0.12	0.06	0.04	0.15	0.52	0.26	0.21	0.21
	1976	0.15	0.09	0.06	0.08	.05*	0.08	0.17	0.13	0.18	0.29	0.54	0.37	0.46
	1977	0.20	0.19	0.13	0.13		0.06	0.18	0.16	0.25	0.38	0.56	0.34	0.38

(continued)

TABLE 10. (continued)

		Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Constit-uent	Year	Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
South Series														
		Leaf												
		%												
P	1971	0.33	0.29	0.30	0.30		0.32	0.31	0.34	0.32	0.38	0.32	0.32	0.36
	1972	0.34	0.29	0.31	0.33		0.34	0.30	0.36	0.37	0.36	0.30	0.34	0.39
	1973	0.35	0.34	0.38	0.39		0.39	0.37	0.39	0.38	0.48	0.36	0.43	0.40
	1974	0.43	0.42	0.43	0.44		0.44	0.42	0.43	0.50	0.49	0.45	0.41	0.54
	1975	0.35	0.32	0.35	0.38	.04*	0.34	0.40	0.36	0.43	0.38	0.37	0.35	0.41
	1976						0.33	0.30	0.37	0.46	0.42	0.32	0.42	0.46
	1977						0.26	0.28	0.29	0.33	0.30	0.32	0.35	0.39
		Grain												
		%												
	1971	0.31	0.03	0.31	0.26		0.33	0.26	0.29	0.31	0.40	0.34		0.44
	1972	0.30	0.29	0.32	0.30		0.31	0.33	0.32	0.35	0.35	0.34	0.30	0.35
	1973	0.32	0.29	0.33	0.34		0.32	0.35	0.32	0.33	0.37	0.34	0.32	0.32
	1974	0.32	0.33	0.32	0.36		0.29	0.34	0.34	0.37	0.37	0.46	0.36	0.33
	1975	0.33	0.33	0.35	0.38		0.36	0.34	0.38	0.40	0.39	0.31	0.38	0.41
	1976						0.36	0.32	0.35	0.35	0.39	0.34	0.41	0.32
	1977						0.32	0.36	0.32	0.37	0.36	0.30	0.46	0.33
		Stover												
		%												
	1972	0.09	0.09	0.09	0.13		0.11	0.08	0.13	0.23	0.20	0.14	0.24	0.31
	1973	0.12	0.10	0.16	0.17		0.14	0.11	0.17	0.27	0.23	0.25	0.31	0.35
	1974	0.13	0.12	0.11	0.11		0.12	0.11	0.10	0.20	0.11	0.17	0.15	0.19
	1975	0.09	0.09	0.11	0.18	.06**	0.09	0.13	0.09	0.19	0.18	0.22	0.17	0.38
	1976						0.10	0.10	0.12	0.36	0.20	0.21	0.24	0.36
	1977						0.10	0.14	0.26	0.27	0.61	0.28	0.30	0.42

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf %												
K	1971	1.90	1.70	1.88	1.88		1.88	1.78	1.78	2.00	2.32	2.51	2.52	2.38
	1972	1.67	1.65	1.79	2.01	0.26*	1.50	1.83	1.97	2.41	1.68	2.01	2.01	2.28
	1973	2.05	2.36	2.40	2.37		2.07	1.85	2.38	2.40	2.39	2.61	2.52	2.40
	1974	2.00	1.64	2.06	2.38		1.79	2.17	1.44	2.32	2.78	2.49	2.87	2.75
	1975	2.95	2.90	3.32	3.26		3.21	2.67	3.02	3.54	3.02	2.31	3.11	3.30
	1976	2.38	2.07	2.04	2.17		2.33	1.95	2.13	2.24	2.68	2.66	3.13	2.09
		Grain %												
	1971	0.51	0.51	0.48	0.47		0.52	0.52	0.50	0.55		0.52		
	1972	0.26	0.29	0.28	0.29		0.31	0.22	0.29	0.28	0.38	0.26	0.32	0.28
	1973	0.36	0.35	0.33	0.35		0.36	0.33	0.32	0.34	0.37	0.36	0.35	0.34
	1974	0.39	0.39	0.37	0.38		0.35	0.36	0.38	0.38	0.40	0.42	0.37	0.41
	1975	0.46	0.46	0.47	0.46		0.52	0.46	0.49	0.55	0.52	0.41	0.52	0.50
	1976	0.40	0.36	0.37	0.36		0.35	0.41	0.37	0.40	0.47	0.43	0.41	0.46
	1977	0.50	0.40	0.47	0.45		0.50	0.56	0.42	0.37	0.48	0.42	0.52	0.46
		Stover %												
	1972	0.40	0.74	1.07	1.20	0.51**	0.50	0.98	1.21	1.30	1.12	1.14	0.99	1.46
	1973	0.87	0.93	1.00	1.28		0.85	0.93	0.89	1.26	1.52	1.81	1.52	2.92
	1974	0.99	0.77	1.00	1.11		0.94	0.73	1.10	1.44	2.54	1.55	1.78	1.82
	1975	1.48	1.54	1.69	1.68		1.36	1.68	1.72	2.28	2.07	2.19	2.28	2.64
	1976	1.36	1.38	1.50	1.08		1.26	1.56	1.34	2.31	1.42	2.03	2.22	2.14

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam					Elliott silt loam				Plainfield loamy sand			
		Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
South Series														
		Leaf %												
K	1971	1.69	1.68	1.76	1.76		1.72	1.53	1.65	1.76	1.82	2.17	2.25	1.95
	1972	1.65	1.58	1.65	1.87	0.21**	1.76	1.73	1.72	1.93	1.62	1.51	1.62	1.94
	1973	1.90	1.86	2.00	2.30		2.50	2.14	2.48	2.59	2.27	2.46	2.70	2.99
	1974	2.45	2.25	2.59	2.46		2.26	2.58	2.55	2.30	2.95	3.47	3.20	2.80
	1975	2.50	2.55	2.63	2.81		2.42	2.65	2.57	2.76	2.57	3.08	2.72	2.58
	1976						2.47	2.61	2.34	2.71	2.62	2.77	2.34	2.28
		Grain %												
	1971	0.48	0.49	0.49	0.46		0.51	0.49	0.46	0.46	0.56	0.48		0.57
	1972	0.27	0.25	0.27	0.26		0.26	0.28	0.24	0.34	0.34	0.28	0.23	0.28
	1973	0.34	0.32	0.33	0.31		0.34	0.39	0.33	0.32	0.36	0.36	0.30	0.29
	1974	0.38	0.43	0.40	0.43		0.38	0.41	0.39	0.41	0.42	0.43	0.43	0.37
	1975	0.49	0.51	0.50	0.53		0.56	0.50	0.57	0.58	0.56	0.54	0.52	0.54
	1976						0.42	0.45	0.45	0.46	0.43	0.42	0.47	0.46
		Stover %												
	1972	0.71	0.60	0.80	1.05		0.80	1.00	1.03	1.15	1.04	1.21	0.99	1.49
	1973	0.91	1.09	1.08	1.25		1.02	1.18	1.10	1.90	1.45	1.64	1.98	1.98
	1974	1.08	1.00	1.29	1.65	0.37*	1.09	0.98	1.40	1.79	1.79	1.75	2.15	2.10
	1975	0.85	0.85	0.82	1.30		0.77	1.18	1.33	1.86	1.16	2.08	1.14	1.79
	1976						1.24	1.26	1.76	1.61	1.91	2.37	2.17	2.06

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf												
		ppm												
Na	1971	366	230	245	241	53**	328	221	252	218	437	321	470	385
	1972	208	236	208	209		261	196	191	223	196	247	289	263
	1973	220	186	198	183		218	163	214	240	292	186	337	170
	1974	376	344	350	312		383	302	287	386	500	472	507	442
	1975	70	81	62	59		83	62	61	60	65	67	71	68
	1976	434	365	264	285		360	285	270	268	628	659	757	302
		Grain												
		ppm												
	1971	3	3	4	3		4	3	1	1		2		
	1972	4	5	3	6		6	2	4	4	4	4	6	4
	1973	7	8	10	9		10	8	10	11	13	11	12	9
	1974	23	18	22	19		21	14	14	16	16	28	21	18
	1975	6	5	7	5		6	7	4	3	5	10	4	4
	1976	7	7	7	10		7	15	8	8	6	9	22	5
		Stover												
		ppm												
	1972	37	36	37	38		34	33	35	41	49	45	36	30
	1973	22	21	18	24		20	20	13	14	188	83	78	36
	1974	39	55	37	32		66	34	15	48	191	142	195	
	1975	32	36	25	29		56	30	25	28	47	49	27	76
	1976	40	41	35	21		--	33	35	34	54	49	81	69
	1977	26	32	29	24		23	16	32	32				

(continued)

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TABLE 10. (continued)

Constituent	Year	Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
		Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
	South Series													
		Leaf												
		ppm												
Na	1971	218	255	247	220		229	271	253	217	204	252	243	267
	1972	191	215	188	190		248	268	277	204	195	230	204	264
	1973	225	193	243	218		217	179	143	247	283	203	268	229
	1974	422	416	368	436		416	337	389	382	492	583	442	458
	1975	90	96	96	133		102	97	70	143	96	132	167	88
	1976						347	321	271	264	276	324	264	253
		Grain												
		ppm												
	1971	3	2	1	2		2	2	3	3	2	2		1
	1972	2	2	4	5		2	4	5	7	4	3		2
	1973	10	15	11	13		8	12	9	11	9	14	2	13
	1974	17	23	15	14		15	25	8	14	14	17	11	11
	1975	8	10	9	9		8	10	7	13	10	13	16	7
	1976						8	1	4	5	4	3	9	5
	1977						2	5	1	6	5	2	1	1
		Stover												
		ppm												
	1972	62	33	42	64		65	40	36	37	36	51	36	39
	1973	25	36	23	31		26	37	65	30	135	77	67	94
	1974	180	43	46	79	87*	61	38	52	96	504	238	206	341
	1975	91	81	74	114		80	74	58	207	179	45	132	57
	1976						70	34	55	67		186	23	88
	1977						52	25	26	23	26	23	20	14

(continued)

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf												
		%												
Ca	1971	0.53	0.58	0.54	0.61	0.05*	0.49	0.55	0.55	0.55	0.43	0.45	0.44	0.53
	1972	0.37	0.44	0.44	0.41		0.35	0.43	0.43	0.42	0.31	0.29	0.38	0.42
	1973	0.60	0.62	0.60	0.80		0.64	0.52	0.62	0.54	0.39	0.55	0.59	0.63
	1974	0.58	0.41	0.62	0.64		0.45	0.67	0.43	0.56	0.59	0.43	0.51	0.61
	1975	0.71	0.66	0.67	0.67		0.64	0.67	0.66	0.56	0.40	0.58	0.63	0.76
	1976	0.79	0.71	0.64	0.62		0.60	0.56	0.60	0.82	0.53	0.67	0.68	0.93
	1977	0.78	0.77	0.74	0.75		0.61	0.68	0.80	0.73	0.55	0.68	0.62	0.60
		Grain												
		ppm												
	1971	47	51	39	43		45	45	38	45			89	
	1972	23	19	18	18		28	20	11	48	26	20	20	16
	1973	18	32	25	24		19	20	25	27	33	30	45	37
	1974	65	56	62	48		77	73	63	41	78	63	79	65
	1975	37	35	30	29		30	34	31	30	33	33	29	42
	1976	53	47	40	59		20	40	31	64	50	50	31	82
	1977	27	53	64	42		43	48	60	34	39	64	64	70
		Stover												
		%												
	1972	0.20	0.29	0.28	0.32		0.17	0.26	0.25	0.30	0.23	0.30	0.34	0.34
	1973	0.19	0.21	0.22	0.28		0.20	0.27	0.18	0.28	0.22	0.35	0.44	0.53
	1974	0.21	0.20	0.23	0.22		0.21	0.18	0.15	0.29	0.33	0.16	0.28	0.41
	1975	0.13	0.16	0.15	0.16		0.16	0.12	0.15	0.22	0.14	0.16	0.13	0.38
	1976	0.23	0.25	0.23	0.19		0.32	0.22	0.11	0.37	0.26	0.21	0.30	0.71
	1977	0.28	0.52	0.45	0.40		0.31	0.33	0.49	0.53	0.28	0.39	0.36	0.54

(continued)

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		%												
Ca	1971	0.42	0.42	0.44	0.48	0.04*	0.49	0.46	0.49	0.48	0.38	0.29	0.33	0.41
	1972	0.33	0.37	0.38	0.34		0.32	0.28	0.37	0.35	0.31	0.31	0.34	0.28
	1973	0.57	0.61	0.60	0.64		0.63	0.53	0.58	0.57	0.53	0.55	0.59	0.42
	1974	0.56	0.52	0.45	0.51		0.53	0.54	0.27	0.57	0.45	0.54	0.42	0.65
	1975	0.62	0.71	0.66	0.61		0.52	0.65	0.59	0.56	0.55	0.67	0.58	0.63
	1976						0.61	0.63	0.86	0.72	0.57	0.66	1.16	1.00
	1977						0.66	0.74	0.93	0.94	0.76	0.62	0.85	0.69
		Grain												
		ppm												
	1971	49	40	58	59		31	61	62	31	37	70		70
	1972	31	21	22	17		16	60	60	85	18	191	41	52
	1973	21	29	24	26		24	21	23	20	19	28	23	52
	1974	58	76	77	77		52	22	52	86	73	105	62	84
	1975	40	43	42	43		40	41	40	40	57	66	56	74
	1976						46	42	35	35	43	44	82	61
	1977						49	36	34	38	48	36	64	71
		Stover												
		%												
	1972	0.26	0.26	0.29	0.28		0.22	0.27	0.27	0.26	0.29	0.29	0.31	0.37
	1973	0.18	0.25	0.25	0.29		0.18	0.20	0.27	0.26	0.23	0.30	0.48	0.50
	1974	0.32	0.28	0.24	0.37		0.28	0.14	0.25	0.31	0.26	0.42	0.54	0.50
	1975	0.23	0.20	0.20	0.29		0.16	0.17	0.17	0.21	0.19	0.27	0.29	0.37
	1976						0.49	0.46	0.71	0.40	0.33	0.43	0.74	0.84
	1977						0.61	0.53	0.59	0.50	0.30	0.47	0.46	0.61

(continued)

TABLE 10. (continued)

Constituent	Year	Soil type Blount silt loam Ck	 1/4	 1/2	 Max	 LSD	 Elliott silt loam Ck	 1/4	 1/2	 Max	 Plainfield loamy sand Ck	 1/4	 1/2	 Max
North Series														
		Leaf %												
Mg	1971	0.28	0.31	0.27	0.21	0.06**	0.30	0.29	0.29	0.21	0.25	0.21	0.20	0.18
	1972	0.20	0.21	0.20	0.14	0.05*	0.21	0.24	0.21	0.17	0.14	0.15	0.18	0.18
	1973	0.27	0.22	0.21	0.19		0.29	0.24	0.17	0.16	0.19	0.19	0.17	0.14
	1974	0.42	0.33	0.36	0.32		0.35	0.41	0.16	0.26	0.29	0.25	0.25	0.20
	1975	0.28	0.30	0.28	0.24	0.03**	0.25	0.27	0.24	0.23	0.32	0.34	0.29	0.27
	1976	0.40	0.33	0.32	0.27	0.08*	0.30	0.35	0.32	0.28	0.40	0.45	0.44	0.32
	1977	0.32	0.31	0.28	0.27		0.34	0.33	0.29	0.28	0.35	0.38	0.34	0.26
		Grain %												
	1971	0.14	0.13	0.13	0.13		0.14	0.14	0.14	0.15		0.14		
	1972	0.08	0.09	0.09	0.08		0.09	0.07	0.09	0.08	0.10	0.08	0.10	0.08
	1973	0.09	0.06	0.09	0.10		0.05	0.09	0.09	0.09	0.10	0.10	0.10	0.09
	1974	0.08	0.09	0.12	0.13		0.12	0.10	0.12	0.13	0.13	0.16	0.15	0.13
	1975	0.12	0.12	0.12	0.12		0.12	0.11	0.12	0.13	0.13	0.11	0.13	0.13
	1976	0.13	0.12	0.12	0.12	0.01*	0.14	0.13	0.12	0.15	0.15	0.14	0.14	0.15
		Stover %												
	1972	0.11	0.16	0.14	0.11		0.11	0.12	0.13	0.12	0.12	0.12	0.15	0.14
	1973	0.12	0.15	0.15	0.13		0.14	0.16	0.15	0.12	0.13	0.20	0.22	0.18
	1974	0.25	0.22	0.25	0.23		0.23	0.17	0.22	0.25	0.22	0.19	0.21	0.16
	1975	0.14	0.16	0.15	0.15		0.18	0.16	0.16	0.16	0.24	0.20	0.16	0.26
	1976	0.20	0.21	0.23	0.16		0.27	0.27	0.21	0.26	0.23	0.24	0.25	0.37
	1977	0.23	0.29	0.26	0.23		0.26	0.26	0.32	0.35	0.25	0.38	0.28	0.30

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		%												
Mg	1971	0.27	0.29	0.26	0.22	0.04**	0.32	0.30	0.28	0.23	0.25	0.17	0.16	0.16
	1972	0.17	0.19	0.16	0.13	0.04**	0.15	0.18	0.18	0.14	0.15	0.15	0.15	0.13
	1973	0.25	0.22	0.18	0.15	0.07**	0.27	0.21	0.21	0.14	0.21	0.19	0.20	0.13
	1974	0.40	0.42	0.43	0.30		0.38	0.37	0.38	0.23	0.31	0.30	0.28	0.31
	1975	0.28	0.26	0.24	0.25		0.25	0.23	0.23	0.21	0.30	0.30	0.29	0.30
	1976						0.32	0.32	0.31	0.28	0.27	0.32	0.41	0.38
	1977						0.34	0.34	0.35	0.34	0.49	0.32	0.40	0.31
		Grain												
		%												
	1971	0.12	0.12	0.12	0.12		0.13	0.13	0.12	0.12	0.14	0.14		0.14
	1972	0.10	0.10	0.10	0.10		0.10	0.10	0.10	0.11	0.11	0.12	0.10	0.11
	1973	0.09	0.08	0.09	0.09		0.10	0.11	0.09	0.09	0.10	0.10	0.11	0.08
	1974	0.10	0.09	0.13	0.15		0.11	0.15	0.15	0.12	0.10	0.17	0.09	0.06
	1975	0.12	0.14	0.12	0.13		0.14	0.13	0.14	0.15	0.15	0.16	0.15	0.16
	1976						0.14	0.13	0.14	0.14	0.15	0.14	0.16	0.12
	1977						0.15	0.15	0.13	0.16	0.16	0.16	0.16	0.16
		Stover												
		%												
	1972	0.13	0.14	0.12	0.10	.02*	0.11	0.13	0.13	0.11	0.12	0.15	0.16	0.15
	1973	0.11	0.18	0.15	0.14	.04*	0.13	0.15	0.17	0.13	0.13	0.16	0.23	0.24
	1974	0.31	0.35	0.25	0.28		0.31	0.22	0.29	0.23	0.19	0.32	0.33	0.25
	1975	0.18	0.18	0.16	0.21		0.14	0.17	0.16	0.15	0.15	0.22	0.22	0.30
	1976						0.30	0.25	0.34	0.18	0.23	0.38	0.39	0.44
	1977						0.42	0.35	0.40	0.31	0.37	0.38	0.41	0.41

(continued)

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TABLE 10. (continued)

		Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
Constituent	Year	Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
North Series														
		Leaf												
		ppm												
Fe	1971	102	104	102	92		100	113	93	94	106	108	92	91
	1972	113	105	101	101		113	109	115	107	92	157	104	94
	1973	123	134	125	132		129	108	143	135	129	132	123	123
	1974	120	129	125	136		122	106	150	136	84	144	94	75
	1975	96	86	109	112		126	107	114	116	77	81	109	98
	1976	133	89	81	100	29*	85	76	63	59	105	102	115	88
		Grain												
		ppm												
	1971	25	21	27	28	5*	25	27	26	34		25		
	1972	12	11	18	16		14	7	14	15	18	14	15	12
	1973	23	31	22	28		25	29	29	35	25	29	29	29
	1974	18	14	18	18		15	16	18	17	13	14	17	19
	1975	16	15	15	18		18	16	16	22	9	11	11	18
	1976	14	13	15	20		16	11	21	28	16	15	16	23
	1977	26	21	28	24		19	22	18	26	20	10	26	27
		Stover												
		ppm												
	1972	332	350	257	300		197	203	620	340	244	292	304	252
	1973	106	128	95	91		92	76	77	86	90	122	94	131
	1974	251	221	217	219		166	167	167	292	203	291	154	146
	1975	80	93	86	90		73	62	86	77	98	80	74	72
	1976	186	157	132	98		139	160	111	101	198	121	185	103
	1977	159	200	185	150		109	109	152	104	191	130	109	88

(continued)

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		ppm												
Fe	1971	90	92	96	85		105	84	102	98	95	91	90	90
	1972	103	116	97	100		110	104	108	98	100	119	110	116
	1973	114	118	114	92		99	109	99	122	100	90	109	107
	1974	144	164	132	155		131	171	157	178	111	123	131	126
	1975	125	128	134	133		119	111	116	120	118	228	78	94
	1976						107	98	97	92	88	98	76	83
	1977						101	104	128	126	130	162	141	106
		Grain												
		ppm												
	1971	24	23	25	27		22	23	27	24	28	24		23
	1972	14	12	17	17		13	15	15	19	11	11	11	15
	1973	26	17	24	28		22	25	25	29	20	29	35	19
	1974	17	19	20	24	4*	19	22	22	26	15	20	20	22
	1975	19	22	24	28	3**	18	22	26	30	19	19	23	24
	1976						20	27	24	30	20	16	28	27
	1977						16	19	22	24	12	9	19	22
		Stover												
		ppm												
	1972	437	359	271	307		454	288	288	967	396	349	645	276
	1973	111	192	157	128		103	94	148	140	121	133	155	122
	1974	261	283	150	230		165	109	150	124	142	344	257	260
	1975	99	67	80	88		112	74	70	75	120	71	71	98
	1976						223	158	150	217	132	126	81	98
	1977						219	159	138	172	213	183	149	183

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf												
		ppm												
Mn	1971	64	59	78	107	28**	55	64	75	131	42	48	94	115
	1972	58	58	62	72	11**	58	56	65	74	39	34	80	102
	1973	48	35	37	41	9*	41	37	34	35	42	29	74	103
	1974	71	55	50	63		62	54	49	49	82	35	84	86
	1975	31	34	29	32		55	33	28	47	32	21	34	30
	1976	50	33	32	24	13*	67	24	23	82	41	29	31	216
	1977	35	33	31	27	6**	44	30	27	68	23	22	17	136
		Grain												
		ppm												
	1971	6.3	4.0	3.7	4.0	1.8*	5.5	4.0	3.0	6.0		4.0		
	1972	4.0	3.2	3.1	3.0	0.6**	4.2	2.3	2.5	2.9	4.5	2.5	5.1	4.5
	1973	7.1	6.9	7.1	6.5		7.8	6.5	5.8	6.3	8.2	6.4	8.9	7.8
	1974	6.9	5.6	5.8	5.8	0.8**	5.8	5.4	5.4	5.7	7.0	5.0	5.6	6.6
	1975	6.1	5.7	4.9	5.1		6.4	5.4	4.8	5.7	5.4	5.3	4.7	7.7
	1976	6.2	5.3	5.1	5.4		6.6	5.2	4.4	6.3	6.6	4.6	4.9	8.0
	1977	7.6	7.0	7.8	7.2		9.8	6.7	6.7	8.1	7.0	5.3	6.9	9.6
		Stover												
		ppm												
	1972	41	42	42	51		27	35	35	46	28	33	71	60
	1973	21	18	19	24		17	19	14	28	19	17	61	44
	1974	44	33	39	42		39	30	25	63	18	56	70	92
	1975	21	20	22	24		25	18	14	46	27	22	27	66
	1976	23	21	18	19		42	16	22	30	19	15	18	138
	1977	35	39	34	29		24	29	28	47	26	23	40	120

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		ppm												
Mn	1971	47	43	51	61	10*	55	56	59	79	37	32	39	88
	1972	51	43	51	59		51	47	64	110	30	42	59	72
	1973	38	31	32	34		32	24	25	34	33	22	54	42
	1974	42	43	36	43		43	39	41	63	42	31	34	50
	1975	53	40	45	58		44	48	47	73	31	35	43	91
	1976						55	42	56	83	42	31	114	140
	1977						46	48	78	103	31	37	60	103
		Grain												
		ppm												
	1971	5.0	4.0	4.0	3.7		6.0	5.0	4.0	4.0	5.0	5.0		6.0
	1972	3.6	2.6	2.6	2.6		3.4	2.6	2.3	3.8	3.3	2.6	2.9	4.1
	1973	7.6	5.6	6.0	5.6	1.2*	7.4	6.8	6.3	5.8	7.0	7.8	6.8	7.8
	1974	5.8	5.4	4.5	4.7	0.9*	8.9	12.6	5.2	5.5	9.2	3.8	4.7	4.5
	1975	6.5	5.4	5.1	6.3		6.1	5.6	6.0	6.6	6.4	5.6	6.3	9.0
	1976						7.4	6.3	5.7	7.2	7.5	4.6	7.2	7.1
	1977						8.0	7.0	7.0	8.3	6.3	6.0	8.6	8.6
		Stover												
		ppm												
	1972	45	34	39	50		53	41	39	79	42	50	75	88
	1973	19	22	19	23		15	15	22	29	19	17	13	38
	1974	46	33	28	44		45	23	31	56	39	38	73	35
	1975	24	17	23	38		21	18	22	32	21	18	20	54
	1976						57	44	61	83	39	39	54	109
	1977						26	26	52	50	19	21	36	73

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf ppm												
Zn	1971	42	80	112	145	20**	51	105	124	168	22	70	111	138
	1972	24	57	85	108	23**	28	67	102	187	14	46	80	155
	1973	21	47	58	112	20**	20	40	84	147	18	66	164	239
	1974	28	46	55	113	38**	28	63	64	95	19	43	103	143
	1975	22	31	63	84	17**	29	68	78	205	24	36	66	307
	1976	35	28	38	57	15**	26	38	46	323	24	44	90	513
	1977	21	22	33	45	7**	16	37	43	193	15	30	41	260
		Grain ppm												
	1971	24	26	32	38	9**	26	32	35	47		27		
	1972	16	25	28	38	10**	22	24	34	38	16	25	41	40
	1973	18	27	36	45	8**	22	33	38	50	17	44	50	68
	1974	20	27	27	36	7**	22	30	37	48	25	30	35	67
	1975	25	25	29	33	6**	22	29	31	54	26	30	30	62
	1976	24	27	26	29	n.s.	19	26	27	61	29	30	32	71
	1977	25	25	25	27	n.s.	21	28	24	40	33	27	26	48
		Stover ppm												
	1972	18	70	108	195	31**	18	77	129	203	16	89	152	215
	1973	22	42	63	162	37**	12	61	82	263	12	86	302	419
	1974	21	22	40	95	25**	11	32	60	246	40	72	160	298
	1975	22	23	31	52	16**	16	29	31	226	75	70	72	393
	1976	23	24	26	39	n.s.	9	44	38	334	43	107	122	688
	1977	37	42	40	54	n.s.	12	53	62	285	71	131	114	428

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	Blount silt loam LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		ppm												
Zn	1971	27	42	57	72	10**	28	55	72	97	19	38	52	87
	1972	18	43	67	115	20**	22	52	97	160	17	42	80	124
	1973	20	45	88	130	30**	22	63	89	175	23	94	171	133
	1974	22	64	83	117	23**	31	70	112	149	22	92	96	136
	1975	14	70	112	179	117**	19	192	139	268	20	11	176	396
	1976						25	92	191	294	32	151	435	540
	1977						21	89	163	278	17	102	188	356
		Grain												
		ppm												
	1971	18	24	25	34	8**	22	28	27	36	13	28		45
	1972	20	25	37	37	9**	22	32	31	46	17	27	31	42
	1973	19	29	38	45	5**	22	39	43	55	19	41	44	56
	1974	21	32	37	47	6**	22	38	42	54	19	45	51	52
	1975	25	26	28	32	5**	22	29	31	54	32	36	33	62
	1976						24	40	54	61	29	42	63	60
	1977						35	33	38	48	30	30	42	44
		Stover												
		ppm												
	1972	15	49	83	177	30**	26	84	126	217	20	89	142	278
	1973	21	62	103	155	49**	18	66	102	541	23	153	284	450
	1974	21	59	107	185	52**	20	64	117	294	25	147	273	373
	1975	14	45	104	191	45**	14	55	96	234	19	125	202	435
	1976						19	112	254	355	31	201	374	--
	1977						14	88	248	330	81	174	258	502

(continued)

TABLE 10. (continued)

Constituent	Year	Soil type Blount silt loam Ck	 1/4	 1/2	 Max	 LSD	 Elliott silt loam Ck	 1/4	 1/2	 Max	 Plainfield loamy sand Ck	 1/4	 1/2	 Max
North Series														
							Leaf ppm							
Cd	1971	0.5	3.1	11.6	35.6	3.5**	0.1	3.4	13.0	37.0	0.1	6.4	14.4	21.3
	1972	0.5	4.3	10.4	23.3	7.5**	0.4	4.8	13.8	28.3	0.2	4.0	8.4	22.2
	1973	0.3	1.3	2.5	7.1	2.3**	0.4	1.6	11.4	16.2	0.4	4.4	8.0	14.8
	1974	0.1	0.3	0.9	3.6	0.4**	0.2	0.4	1.5	4.5	0.3	0.8	2.8	6.3
	1975	0.7	1.2	1.9	5.9	1.0**	0.4	1.9	2.9	19.9	0.3	0.5	2.8	11.4
	1976	0.3	0.5	1.3	2.9	0.3**	0.3	0.5	1.7	33.6	0.2	0.9	2.2	37.2
	1977	0.2	0.5	1.1	2.1	0.5**	0.3	0.8	1.5	13.5	0.4	1.2	1.3	13.9
							Grain ppm							
	1971	0.15	0.36	0.70	1.37	0.16**	0.10	0.54	0.97	1.36	--	0.28	--	--
	1972	0.15	0.27	0.43	0.89	0.23**	<0.06	0.29	0.67	0.88	0.12	0.32	0.77	0.84
	1973	0.16	0.20	0.27	0.44	0.18*	0.07	0.15	0.26	0.64	0.25	0.45	0.26	0.64
	1974	0.18	0.17	0.15	0.23	n.s.	0.22	0.20	0.16	0.52	0.18	0.16	0.28	0.71
	1975	0.15	0.15	0.22	0.17	n.s.	0.17	0.15	0.19	0.41	0.22	0.12	0.14	0.42
	1976	0.14	0.14	0.13	0.16	n.s.	0.16	0.21	0.12	0.77	0.12	0.15	0.16	0.48
	1977	0.10	<0.06	0.07	<0.06	n.s.	<0.06	<0.06	<0.06	0.32	<0.06	<0.06	0.09	0.44
							Stover ppm							
	1972	0.7	7.6	11.6	34.7	9.4**	0.7	7.9	13.9	33.2	0.4	11.0	16.5	26.8
	1973	0.6	1.0	2.6	13.1	2.2**	0.3	0.9	2.9	21.4	0.3	5.4	10.5	20.2
	1974	0.3	0.4	0.9	2.5	0.4**	0.3	0.4	0.9	18.5	0.5	0.9	5.0	16.6
	1975	0.4	0.4	0.8	1.7	0.4**	0.4	0.5	0.9	14.7	0.3	0.5	0.9	16.8
	1976	0.3	0.5	0.7	1.8	0.5**	0.4	0.5	1.2	30.4	0.9	2.0	1.7	33.0
	1977	0.5	1.2	1.1	2.6	1.1*	0.2	0.7	1.8	25.0	0.8	1.4	2.0	23.7

(continued)

TABLE 10. (continued)

		Soil type												
Constituent		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
	Year	Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
South Series														
		Leaf												
		ppm												
Cd	1971	0.2	1.4	5.1	14.4	3.1**	0.2	1.0	5.0	17.0	0.1	3.1	11.2	19.6
	1972	0.4	2.6	5.6	17.2	2.7**	0.4	3.4	6.4	18.6	0.6	2.4	5.9	14.3
	1973	1.3	2.3	5.1	9.8	3.6**	1.5	1.3	4.8	10.7	0.8	4.9	8.6	9.5
	1974	0.2	0.6	1.2	3.6	1.4**	0.2	0.8	2.8	6.1	0.2	1.6	2.2	5.1
	1975	0.3	3.9	8.6	12.2	7.6*	0.5	7.0	8.3	16.4	0.5	4.9	9.2	12.4
	1976						0.6	3.7	21.4	27.3	0.9	9.2	40.0	38.8
	1977						0.4	4.9	15.2	19.3	0.7	5.7	17.2	22.7
		Grain												
		ppm												
	1971	<0.06	0.09	0.27	0.59	0.22**	<0.06	0.22	0.26	0.68	<0.06	0.19		0.87
	1972	0.10	0.21	0.57	0.96	0.33**	0.17	0.49	0.53	1.29	0.22	0.27	0.87	0.94
	1973	0.14	0.19	0.39	0.54	0.24**	0.24	0.27	0.35	0.49	0.15	0.33	0.27	1.07
	1974	0.14	0.18	0.51	0.55	0.35*	0.09	0.16	0.31	0.60	0.09	0.40	0.50	0.64
	1975	<0.06	0.17	0.33	0.50	0.10**	<0.06	0.15	0.35	0.41	<0.06	0.23	0.42	0.61
	1976						0.06	0.10	0.46	0.52	<0.06	0.33	0.48	0.60
	1977						0.06	0.18	0.41	0.49	0.18	0.26	0.26	0.79
		Stover												
		ppm												
	1972	0.6	7.0	13.4	23.6	9.5**	0.9	10.0	15.6	24.0	1.1	9.8	19.3	34.5
	1973	0.2	1.3	4.2	14.2	5.6**	0.3	1.3	3.3	22.6	0.5	9.4	10.4	26.7
	1974	0.4	1.2	4.2	17.9	9.9**	0.1	0.8	3.8	25.2	0.8	8.7	18.2	17.8
	1975	0.7	2.6	9.2	20.2	4.2**	0.8	2.5	6.1	17.1	0.7	4.5	18.4	25.0
	1976						0.8	8.8	29.3	33.2	1.3	8.9	27.3	49.4
	1977						0.5	4.9	21.6	24.4	1.0	9.5	17.3	32.9

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf												
		ppm												
Cu	1971	9.0	11.4	11.9	10.7	0.9**	10.2	13.2	12.8	6.4	5.0	9.0	9.0	10.6
	1972	11.8	12.2	14.0	14.9	2.5**	11.6	9.6	12.7	13.9	10.5	12.5	16.2	12.2
	1973	9.3	8.7	8.7	9.4		5.8	7.5	9.9	5.6	7.9	8.7	10.1	11.1
	1974	11.4	9.6	9.7	11.2		11.1	9.8	9.9	9.0	5.6	6.2	10.9	11.9
	1975	7.0	7.7	9.8	10.3		9.5	8.6	9.9	12.4	5.4	4.4	9.9	13.2
	1976	10.6	7.9	7.9	9.2		8.0	6.9	8.0	9.2	5.0	6.5	8.6	15.3
	1977	6.1	5.9	6.9	7.3	0.3*	5.3	6.4	7.8	8.4	4.5	3.6	5.0	9.3
		Grain												
		ppm												
	1971	6.9	9.4	8.4	8.0	1.3**	8.4	8.3	8.8	7.1		7.5		
	1972	2.4	3.4	4.2	3.6	1.1*	2.6	2.8	3.4	2.1	1.5	2.4	2.7	2.8
	1973	3.1	2.2	2.6	3.7		2.3	2.4	2.5	1.8	1.4	2.2	2.2	2.8
	1974	3.2	3.0	3.7	3.0		2.6	2.8	3.1	2.3	1.5	2.6	6.4	3.4
	1975	2.0	2.0	2.1	2.3		2.6	2.2	1.9	1.2	1.7	2.3	1.7	2.6
	1976	1.6	1.8	2.0	2.1		1.5	2.5	1.9	1.8	2.0	2.1	2.2	1.8
	1977	1.2	1.7	1.3	1.2		1.5	1.4	0.9	1.7	1.2	1.2	1.5	1.9
		Stover												
		ppm												
	1972	5.0	8.8	12.7	16.6	6.3*	3.7	7.3	19.3	10.5	5.3	19.6	11.9	11.0
	1973	3.4	4.4	3.8	6.4		1.9	2.6	3.7	3.4	2.6	5.8	7.4	8.5
	1974	4.0	3.9	4.2	5.5	1.2*	4.0	3.1	5.0	10.8	2.4	4.4	4.4	7.5
	1975	5.4	4.6	5.3	6.3		6.4	5.2	5.6	6.1	5.1	4.5	4.7	10.2
	1976	5.1	5.4	5.2	5.9		4.2	5.5	6.9	8.1	5.5	4.7	6.9	11.8
	1977	7.7	7.0	8.9	8.8		8.5	10.8	9.1	8.6	4.1	8.1	8.1	12.7

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf ppm												
Cu	1971	8.9	9.4	9.7	9.3	0.5*	9.0	9.6	10.8	10.4	7.3	9.1	9.6	9.9
	1972	11.2	11.7	12.6	14.3		10.1	10.7	12.4	11.0	10.4	12.4	12.4	14.8
	1973	10.3	6.9	6.2	6.1		4.6	6.2	5.8	6.2	7.9	5.9	7.9	8.8
	1974	9.8	11.8	9.9	11.1		10.0	9.8	10.3	11.7	7.0	8.1	10.0	13.3
	1975	10.6	10.4	11.3	13.1		8.3	13.2	11.7	12.2	5.7	11.1	10.6	14.7
	1976						8.3	9.7	14.7	11.6	7.7	9.7	13.0	17.2
	1977						8.0	9.7	10.6	11.3	4.6	7.8	9.7	13.3
		Grain ppm												
	1971	2.9	2.9	2.5	2.5		2.5	2.4	3.4	1.6	1.6	2.5		4.4
	1972	2.7	3.3	4.3	3.3		2.0	3.6	2.7	2.8	2.0	3.0	2.1	3.3
	1973	2.5	3.1	2.8	2.7		2.6	3.6	3.2	2.3	2.1	2.7	2.3	2.8
	1974	2.8	2.9	3.0	3.9		2.4	2.7	1.8	2.4	1.8	2.5	3.2	2.2
	1975	2.6	2.6	2.7	2.6		2.6	3.4	2.5	3.6	2.3	2.8	3.9	2.7
	1976						1.3	2.0	1.3	1.5	0.9	1.5	1.3	0.9
	1977						2.7	2.2	2.3	1.9	2.3	1.6	1.5	2.0
		Stover ppm												
	1972	3.9	4.3	5.5	6.2		3.1	4.2	4.5	6.0	3.7	7.6	7.6	5.5
	1973	4.2	4.6	5.3	4.6		3.8	4.2	5.3	5.9	2.3	9.5	7.9	8.8
	1974	5.8	6.1	4.6	7.0		6.6	3.6	8.4	6.8	2.0	5.6	7.8	12.6
	1975	5.6	5.8	6.0	7.1	1.0*	5.6	5.0	5.3	5.2	4.9	6.3	6.4	10.4
	1976						8.5	9.7	10.0	11.1	5.8	8.9	10.3	13.5
	1977						6.3	7.1	9.3	8.8	5.7	9.5	10.2	13.2

(continued)

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf ppm												
Ni	1971	1.2	1.3	1.4	1.2		1.2	1.2	1.6	1.2	1.3	1.2	1.6	1.4
	1972	0.9	1.0	0.9	1.1		0.8	0.6	1.3	1.4	1.2	1.4	5.3	2.0
	1973	<0.6	2.4	2.0	2.3		<0.6	1.7	1.5	1.2	<0.6	<0.6	3.4	2.4
	1974	<0.6	<0.6	<0.6	0.7		0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.1	0.9
	1975	<0.6	<0.6	<0.6	<0.6		<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
	1976	0.7	0.9	<0.6	0.8		0.7	0.8	0.8	2.7	0.8	2.0	1.2	6.2
	1977	1.1	1.2	0.8	0.8		<0.6	0.6	2.4	1.4	1.4	0.8	1.6	2.5
		Grain ppm												
	1971	<0.6	<0.6	<0.6	<0.6		<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
	1972	0.6	<0.6	0.9	<0.6		0.6	<0.6	<0.6	<0.6	<0.6	<0.6	1.8	2.1
	1973	<0.6	0.6	0.6	0.8		0.7	<0.6	<0.6	<0.6	0.6	<0.6	1.1	1.5
	1974	0.7	0.9	1.1	0.9		0.7	1.5	1.7	0.9	0.6	0.9	2.3	4.0
	1976	<0.6	<0.6	<0.6	0.8		<0.6	<0.6	0.6	2.1	<0.6	1.6	0.9	9.5
	1977	0.8	<0.6	1.0	<0.6		<0.6	0.6	<0.6	1.2	0.8	<0.6	0.6	2.9
		Stover ppm												
	1972	0.8	1.2	1.1	1.1		1.1	0.8	2.0	1.8	1.0	1.6	1.6	1.8
	1973	0.6	0.9	0.8	1.2	0.4*	0.6	0.8	1.0	1.0	0.6	0.6	4.2	4.4
	1974	<0.6	<0.6	<0.6	0.8		<0.6	<0.6	<0.6	5.0	<0.6	0.6	0.6	2.4
	1975	<0.6	0.6	<0.6	0.8		0.6	<0.6	0.7	1.9	0.8	0.7	0.7	5.4
	1976	<0.6	0.8	0.8	0.7		<0.6	<0.6	1.5	2.3	1.6	<0.6	0.8	10.9
	1977	0.7	0.9	1.3	<0.6		0.6	0.6	1.0	2.0	0.6	<0.6	<0.6	3.7

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		ppm												
Ni	1971	1.3	1.3	1.2	1.2		1.3	1.2	1.5	1.3	1.2	1.3	1.5	1.3
	1972	1.4	1.6	1.1	1.6		1.5	1.0	1.3	1.4	1.6	1.4	1.1	1.8
	1973	1.1	0.9	0.9	0.9		0.7	0.9	1.2	1.2	0.6	0.9	1.6	1.2
	1974	<0.6	<0.6	<0.6	<0.6		<0.6	0.6	0.6	<0.6	<0.6	<0.6	<0.6	<0.6
	1975	0.8	0.7	0.6	0.9		0.6	0.9	<0.6	0.3	0.7	0.8	1.7	2.8
	1976						<0.6	<0.6	1.0	1.5	<0.6	<0.6	2.0	3.6
	1977						0.7	0.8	1.1	1.7	0.6	<0.6	0.7	1.6
		Grain												
		ppm												
	1971	<0.6	<0.6	1.0	0.6		0.8	<0.6	0.8	0.8	<0.6	1.8		2.2
	1972	0.9	0.6	1.6	1.2		<0.6	1.2	<0.6	1.4	0.8	1.3	1.4	3.0
	1973	0.6	0.9	0.7	0.8		1.1	0.8	0.9	1.2	1.2	0.9	0.9	2.2
	1974	0.7	0.7	0.8	0.9		<0.6	0.7	0.9	1.2	<0.6	0.6	2.1	2.7
	1975	2.2	2.8	4.2	4.2		1.9	2.5	1.6	4.2	2.1	3.4	4.4	5.8
	1976						<0.6	<0.6	1.1	2.3	<0.6	0.8	3.1	7.3
	1977						<0.6	<0.6	<0.6	1.3	<0.6	<0.6	2.1	5.1
		Stover												
		ppm												
	1972	1.5	2.1	1.7	1.4		1.8	1.8	1.4	2.6	1.4	1.4	2.7	2.3
	1973	<0.6	1.0	1.5	0.7		<0.6	<0.6	1.1	1.6	<0.6	1.2	2.7	4.5
	1974	0.7	0.7	<0.6	0.8		<0.6	<0.6	<0.6	1.2	<0.6	0.6	2.2	4.7
	1975	0.8	1.0	0.7	0.8		0.8	0.9	<0.6	1.6	0.7	1.2	1.4	6.5
	1976						<0.6	<0.6	0.8	2.9	<0.6	0.8	3.9	3.2
	1977						1.0	<0.6	1.0	1.7	0.7	2.7	2.3	3.8

(continued)

TABLE 10. (continued)

Constit-uent	Year	Soil type Blount silt loam Ck	1/4	1/2	Max	LSD	Elliott silt loam Ck	1/4	1/2	Max	Plainfield loamy sand Ck	1/4	1/2	Max
North Series														
		Leaf ppm												
Cr	1971	1.0	0.8	1.0	1.0		1.0	1.0	1.2	1.2	1.1	1.2	1.7	1.0
	1972	1.3	1.5	1.4	1.1		2.2	1.5	1.3	1.2	1.4	0.9	1.4	1.1
	1973	0.9	1.2	1.6	1.0		1.1	0.9	1.4	1.0	1.0	1.2	1.0	1.2
	1974	<0.6	<0.6	0.7	0.6		<0.6	<0.6	<0.6	<0.6	<0.6	0.7	0.6	<0.6
	1975	0.7	1.6	0.6	1.2		2.1	0.6	2.9	1.3	0.8	0.8	1.3	1.3
	1976	<0.6	<0.6	0.7	<0.6		<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	0.7
	1977	1.3	0.8	0.9	1.1		2.7	<0.6	2.1	0.6	2.4	1.3	1.3	0.9
		Grain ppm												
	1971	0.2	0.2	0.3	0.3		0.2	0.2	0.4	0.4			0.4	
	1972	0.3	0.3	0.4	0.3		0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.3
	1973	0.4	0.4	0.4	0.3		0.5	0.4	<0.2	0.6	0.4	0.3	0.3	0.4
	1974	0.6	0.8	0.6	0.6		0.8	0.7	1.7	0.5	0.8	0.4	0.4	0.2
	1975	0.2	0.3	0.2	0.4		0.3	0.3	0.1	0.1	0.2	0.2	0.3	0.2
	1976	0.2	0.1	0.1	<0.1		0.2	0.2	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	1977	0.5	0.7	0.4	0.9		0.6	0.9	0.8	0.2	1.4	0.2	0.2	0.6
		Stover ppm												
	1972	1.9	2.7	2.9	3.1		1.9	2.2	2.2	1.7	2.1	3.2	3.5	2.1
	1973	0.8	2.0	0.7	1.2		0.7	1.0	1.0	0.7	0.7	2.4	1.3	2.7
	1974	1.4	2.1	1.8	1.7		2.0	1.1	1.3	12.2	1.1	1.3	1.3	2.1
	1975	0.8	0.9	1.1	1.0		0.4	0.4	0.8	0.6	0.4	1.0	1.0	0.4
	1976	1.2	0.7	2.4	1.3		<0.6	<0.6	2.3	<0.6	1.5	<0.6	3.4	<0.6
	1977	2.2	<0.6	<0.6	<0.6		2.0	<0.6	<0.6	<0.6	0.9	1.4	<0.6	1.0

(continued)

TABLE 10. (continued)

Constit-uent	Year	Soil type												
		Blount silt loam					Elliott silt loam				Plainfield loamy sand			
		Ck	1/4	1/2	Max	LSD	Ck	1/4	1/2	Max	Ck	1/4	1/2	Max
South Series														
		Leaf												
		ppm												
Cr	1971	1.0	1.0	1.0	1.0		0.9	1.0	1.1	1.0	1.1	1.2	1.5	1.0
	1972	1.1	1.1	0.9	1.1		1.0	0.9	1.0	1.1	1.4	1.4	1.0	1.3
	1973	1.2	0.9	1.6	1.1		1.2	1.7	1.6	1.9	1.2	1.2	1.2	1.2
	1974	0.6	0.6	<0.6	0.7		0.9	2.0	0.9	0.6	<0.6	1.2	0.8	0.8
	1975	0.9	1.3	0.7	0.7		<0.6	<0.6	<0.6	0.8	<0.6	1.3	4.0	<0.6
	1976						<0.6	0.6	1.2	1.9	<0.6	1.7	0.8	0.6
	1977						<0.6	1.4	1.0	0.6	0.3	6.2	0.8	3.6
		Grain												
		ppm												
	1971	0.2	0.5	0.8	0.2		0.2	0.6	0.6	0.2	0.2	0.9		0.6
	1972	0.3	0.4	0.8	0.2		0.6	0.4	0.6	0.8	0.1	0.2	0.4	0.6
	1973	0.2	0.3	0.4	0.3		0.1	0.2	0.4	0.1	0.4	0.3	0.3	0.3
	1974	0.7	0.3	0.7	0.5		0.4	1.0	0.4	2.4	1.4	0.3	0.2	0.5
	1975	1.0	2.1	0.4	0.8		2.3	0.8	1.3	-	0.7	-	-	-
	1976						0.7	0.7	0.6	0.3	0.2	<0.1	1.0	0.6
	1977						1.0	0.4	2.6	0.4	0.5	1.1	0.6	0.5
		Stover												
		ppm												
	1972	2.1	2.7	2.2	1.8		1.9	2.2	3.5	1.7	2.2	3.4	2.8	2.9
	1973	0.9	2.0	1.4	1.0		0.7	1.1	0.9	1.6	0.7	1.0	1.4	1.1
	1974	3.9	5.6	3.8	4.5		1.0	1.1	0.6	4.2	0.9	3.0	4.1	8.4
	1975	2.2	2.1	2.5	2.4		2.6	2.5	2.3	2.6	2.0	3.0	2.4	3.0
	1976						1.3	1.7	0.6	4.4	0.4	2.7	1.9	1.9
	1977						2.6	1.7	1.4	1.1	1.7	2.9	2.8	2.2

(continued)

TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
North Series														
		Leaf												
		ppm												
Pb	1971	2.4	2.8	1.7	4.3		2.2	3.0	2.2	1.4	2.2	2.9	3.6	1.4
	1972	4.1	3.8	3.9	3.9		3.9	4.3	3.9	3.5	3.3	5.5	5.5	4.7
	1973	4.9	4.0	3.5	4.6		3.7	3.8	2.0	3.2	5.7	6.6	5.0	3.2
	1974	2.7	2.2	2.3	2.7		2.8	2.6	1.6	1.4	1.9	3.6	3.3	1.6
	1975	2.9	2.3	1.7	1.7		1.9	1.2	2.1	1.6	1.4	1.2	3.1	0.8
	1976	2.5	2.9	1.7	2.4		2.4	1.0	2.5	2.4	3.1	3.5	3.1	2.4
	1977	1.8	2.1	1.9	1.6		2.2	1.7	1.3	2.5	1.4	1.3	1.9	2.8
		Grain												
		ppm												
	1971	2.0	1.8	2.4	3.7		1.4	3.6	1.4	2.9			1.3	
	1972	3.1	2.0	1.6	1.8		2.8	3.0	1.5	2.6	2.4	1.8	2.2	3.7
	1973	1.4	1.4	1.6	1.7		1.6	2.8	2.1	1.0	1.5	1.5	1.0	5.4
	1974	0.9	0.5	1.0	1.0		0.7	1.2	1.0	0.5	1.2	0.5	1.2	2.1
	1975	1.8	1.6	2.4	2.4		0.9	3.8	2.1	2.6	2.3	3.4	1.7	3.8
	1976	2.1	1.2	1.2	1.2		0.5	0.9	1.2	1.8	1.9	0.7	1.4	0.7
	1977	1.4	1.7	1.4	1.9		0.7	1.6	1.6	2.0	2.3	1.8	1.6	1.6
		Stover												
		ppm												
	1972	3.3	6.0	7.0	9.2	2.8**	3.2	4.6	8.6	7.7	7.5	13.5	9.1	5.9
	1973	2.7	3.4	3.3	3.0		2.8	1.5	1.7	2.0	3.8	4.7	3.8	5.1
	1974	2.9	2.7	3.0	4.1		2.9	3.6	2.8	7.3	3.2	5.3	3.2	1.4
	1975	2.5	2.7	3.0	2.5		3.1	3.2	2.7	1.7	3.8	4.0	1.7	2.8
	1976	3.7	3.4	2.2	2.5		2.1	3.8	2.3	1.6	3.2	2.5	2.5	3.8
	1977	2.5	4.1	3.8	4.1		2.8	2.7	3.2	3.0	4.8	4.3	2.7	3.0

(continued)

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TABLE 10. (continued)

Constituent	Year	Blount silt loam Ck	Blount silt loam 1/4	Blount silt loam 1/2	Blount silt loam Max	LSD	Elliott silt loam Ck	Elliott silt loam 1/4	Elliott silt loam 1/2	Elliott silt loam Max	Plainfield loamy sand Ck	Plainfield loamy sand 1/4	Plainfield loamy sand 1/2	Plainfield loamy sand Max
South Series														
		Leaf												
		ppm												
Pb	1971	3.0	1.9	1.8			2.3	2.4	2.1		2.7	2.4	1.6	
	1972	3.7	3.2	3.6	4.0		3.8	1.9	3.0	3.8	3.8	3.8	3.8	4.2
	1973	2.0	1.9	2.2	2.0		1.7	1.8	2.0	1.8	3.0	2.3	1.8	1.3
	1974	2.1	2.6	2.2	1.8		2.3	2.4	2.9	3.4	2.1	2.5	1.2	2.7
	1975	1.8	2.2	2.2	3.0		1.9	1.9	1.3	2.3	2.7	5.5	3.9	1.2
	1976						3.0	3.0	2.5	2.3	3.3	4.3	3.7	3.0
	1977						1.1	1.2	1.2	1.1	1.8	2.4	1.8	2.2
		Grain												
		ppm												
	1971	2.3	2.3	2.5	1.2		1.8		4.0	1.5	2.5	3.3		1.1
	1972	1.5	1.9	0.9	1.4	0.6*	1.7		1.0	2.1	-	-	1.0	1.0
	1973	2.7	1.4	1.9	1.6		3.3	1.7	1.0	1.0	2.2	2.2	2.9	3.2
	1974	1.4	1.0	0.8	1.3		1.0	1.2	1.2	0.5	0.8	1.2	0.8	0.8
	1975	2.4	4.2	4.0	4.8		1.2	2.7	3.5	4.2	2.7	3.6	5.9	3.5
	1976						0.9	1.6	1.0	2.6	1.3	0.4	1.0	1.2
	1977						1.2	1.0	1.7	0.6	1.8	1.2	0.5	3.7

(continued)

TABLE 10. (continued)

Constit-uent	Year	Soil type Blount silt loam Ck	 1/4	 1/2	 Max	 LSD	 Elliott silt loam Ck	 1/4	 1/2	 Max	 Plainfield loamy sand Ck	 1/4	 1/2	 Max
South Series														
							Stover							
							ppm							
	1972	4.2	2.6	5.1	5.7		4.5	4.5	5.4	4.1	6.3	9.5	8.1	5.4
	1973	5.6	4.9	5.6	4.2		5.7	5.1	4.5	7.6	7.1	7.1	10.0	6.1
	1974	3.9	3.5	2.7	3.5		3.2	1.6	1.4	2.2	2.0	3.0	3.2	1.6
	1975	2.4	2.8	2.6	2.7		2.4	3.8	2.5	1.9	3.3	3.6	1.9	2.2
	1976						4.1	4.6	9.0	5.7	3.6	4.2	2.4	5.7
	1977						4.9	3.0	1.8	3.0	3.3	4.2	3.0	4.2

a/ Concentrations were calculated on a dry weight basis.

b/ All three soil types were represented in north and south series.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

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concentrations in stover very little. Concentrations of P in corn plant tissues were seldom affected by sludge applications. Levels of P in leaf and grain samples from all plots were in the range required for high yields and did not change with successive years of applying sludge. Potassium concentrations in all tissues were generally in the range required for high yields. Levels of K were seldom affected by sludge applications. Sludge supplied only small amounts of K, but apparently the annual broadcast application of K fertilizer across all plots was adequate to maintain ample available supplies of the element. Sodium concentrations in all tissues were highly variable from year to year and in comparison to leaves the grain contained low levels of the element.

Sodium concentrations in all tissues were highly variable from year to year and in comparison to leaves the grain contained low levels of the element. Sludge applications may have caused increased Ca concentrations in leaves from Blount silt loam plots in 1971, but such increases were never observed thereafter. Concentrations of Mg in corn leaves from Blount silt loam plots were frequently less where sludge had been applied as compared to the use of only inorganic fertilizers. A similar trend was found for other soil types. Successive years of applying sludge did not cause lower concentrations of Mg in leaves than were observed in the early years of the study. Lower Mg concentrations in grain, that could be attributed to sludge application, were observed only one year (1976) from samples collected from Blount silt loam plots in the north series. Concentrations of Fe were affected by sludge applications in leaf tissues only in 1976. During the first and last 2 years grain from Blount silt loam plots in the north and south series, respectively, had higher Fe concentrations where sludge was applied at maximum amounts. There was no indication that Fe contents of grain increased with successive years of applying sludge. During the early years of the study Mn concentrations appeared to be increased in corn leaves by sludge applications. But during the last 2 years of the study Mn concentrations in leaves from Blount silt loam plots in the north series were significantly less where sludge was applied at maximum amounts. On Blount silt loam plots, in both the north and south series, corn grain from sludge-treated plots contained less Mn than grain from control plots. However, a decrease in grain-Mn contents attributable to sludge applications was not confirmed by results from Elliott silt loam and Plainfield loamy sand plots.

Zinc concentrations were increased in all plant tissues by annual sludge applications. Where sludge applications (Blount silt loam plots in the north series) were terminated after 1973, Zn concentration in grain and stover from plots previously treated with sludge were not significantly different during the last 2 years from those in grain and stover from control plots. Concentrations of Zn in leaves from plots which had previously received maximum-sludge-treatments were significantly higher than those in leaves from control plots during the last year of the study, but levels were less than half those from the last crop year affected by annual sludge applications (1974). Where sludge was applied each year, Cd concentrations were significantly higher in all tissues as compared to concentrations in tissues collected from control plots. Cadmium contents of all tissues varied in proportion to amounts of sludge applied each year and were affected very little from amounts accumulated from sludge applications made in previous years. After sludge applications were terminated (Blount silt loam, north series, 1973), Cd concentration in grain from sludge treated plots were not significantly higher than those found in grain from control plots. Concentrations of Cd in leaf and stover samples from sludge-treated plots continued to be significantly higher than in samples from control plots. But in most years Cd concentrations were two to six times less in leaf and stover samples collected after sludge application were terminated than in years when applications were made annually.

Digested sludge applications were continued on plots in the south series and on maximum-sludge-treated Elliott silt loam and Plainfield loamy sand plots in the north series through the 1976 growing season. In 1977, soil cation exchange capacities varied from about 17 meq/100g for control to 20 meq/100g for maximum-sludge-treated Elliott silt loam in the south series. Cation exchange capacities for Plainfield loamy sand varied from about 5 meq/100g for controls to 10 meq/100g for maximum-sludge-treated soil. These two soil types represented extreme differences in cation exchange capacities, but these differences were not reflected by differences in accumulations of Zn and Cd in corn plant tissues.

Concentrations of Cu appeard to be increased in plant tissues by sludge applications during the early years of study, but after successive years of sludge irrigation there was little evidence that Cu contents were changed as a result of its addition to soils as a constituent of sludge. Concentrations of Ni, Cr, and Pb were seldom increased, if at all, as a result of sludge applications. Corn stover grown on maximum-sludge-treated Blount silt loam plots (north series) in 1973 had higher Ni concentrations than stover from control plots. In 1976 all tissues collected from maximum-sludge-treated Plainfield loamy sand appeared to have had higher Ni concentrations than tissues from control plots. Contents of Ni during this particular year were also higher than in other years. There was no evidence that Cr concentrations in any tissue were affected by sludge treatments. Concentrations of Pb were higher in stover samples from sludge-treated Blount silt loam plots (north series) than in stover samples from control plots, only during 1972. Significant accumulations of Pb were not observed in any other tissue, nor in stover in any other year.

SECTION 5

LONG-TERM PLOT STUDIES

CONTINUOUS CORN ON PLOTS OF BLOUNT SILT LOAM

General Description

Four replications of 6.1 by 12.2 m plots with four sludge treatments randomized within blocks were established in 1968 on Blount silt loam soil (Aeric ochraqualf, fine, illitic, mesic) occupying part of the cultivated area on the Northeast Agronomy Research Center near Joliet, Ill. Digested sludge was applied by furrow irrigation first in 1968 and annually thereafter during the growing season and sometimes during the fall after grain harvest. All plots were annually fertilized with a broadcast application of KCl to supply 134 kg K/ha, and control (zero liquid sludge) plots were further treated with annual broadcast fertilizer applications supplying 268 kg N/ha and 134 kg P/ha. As often as weather conditions permitted, liquid digested sludge was transported by truck-trailer tanks from MSD of Chicago Southwest or Calumet wastewater treatment plants and applied at liquid depths of 25.4 mm (maximum), 12.7 mm (one-half maximum), and 6.4 mm (one-fourth maximum) to each of the appropriate plots on the same day.

Immediately after ridges and furrows were established, corn (Zea mays L.) was planted at rates calculated to give a plant population of 60,000 plants per hectare on top of ridges spaced 76 cm apart. In general, sludge was applied for the first time each year when corn plants had reached a height of about 15 cm.

Samples of sludge, soil, and plant tissues were collected and analyzed by the same methods and procedures as previously described in section I of this report.

Discussion of Results

Sludge loading rates--

Annual and accumulative amounts of liquid digested sludge, along with calculated dry weight amounts of solids, from 1969 through 1977 are shown in Table 11. Year to year loading rates varied because weather conditions affecting sludge dewatering rates were highly variable. Amounts of solids applied on plots varied not only because of the variable liquid loading rates, but because the suspended solids contents of sludge varied from year to year and from one batch to another. The variations were seldom off-setting because generally in years of above normal rainfall contents of suspended solids in sludge were lower than in years of below normal rainfall.

TABLE 11. ANNUAL DIGESTED SLUDGE LOADING RATES AND TOTAL ACCUMULATIONS ON MAXIMUM-SLUDGE-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN.

	Liquid sludge applied (cm)		Dry Solids applied (mt/ha)	
Year	Annual	Accumul.	Annual	Accumul.
1968	17.1	17.1	51.52	51.52
1969	25.4	42.5	48.31	99.83
1970	22.9	65.4	52.67	152.50
1971	38.1	103.5	128.37	280.87
1972	12.7	116.2	25.61	306.48
1973	27.9	144.1	62.15	368.63
1974	17.8	161.9	48.72	417.35
1975	12.7	174.6	32.56	449.91
1976	17.8	192.4	54.44	504.35
1977	15.2	207.6	52.29	556.64

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Average concentrations of several elements in sludges, along with dry weight of amounts applied annually are shown in Table 12. It is noteworthy that about 3,000-, 700-, 180-, and 140- kg/ha of Zn, Cu, Ni, and Cd, respectively, were accumulatively applied, as constituents of sludge, on maximum-treated plots.

Changes in Chemical Properties of Soil--

As may be seen in Table 13, several chemical properties of Blount silt loam soil were changed by sludge applications. In every year maximum sludge applications caused increased concentrations of total N and organic-C in the 0 to 15 and 15 to 30 cm depths of soil. Frequently, ½-maximum-sludge applications significantly increase total N and organic-C concentrations. Surface soil of maximum-sludge-treated plots contained significantly higher concentrations of total N and organic-C during the last four years of the study than were present in the soil in 1971. However, during the last 4 years neither total N nor organic-C concentrations were changed in the soil as a result of accumulative applications of sludge. Apparently, an equilibrium condition between additions and losses of N and C had been established by 1974 and concentrations at equilibrium depended on annual loading rates. There was no idication that total N and organic-C concentrations below 30 cm, were affected by sludge applications. Total P concentrations were increased in both 0 to 15 and 15 to 30 cm depths of the soil by sludge applications. Accumulative maximum sludge applications were reflected by increasing total P concentrations in the soil surface through 1975 and through the last year of the study concentrations were markedly higher in the 15 to 30 cm soil depth. Concentrations of P below soil depth of 30 cm were not affected by sludge applications. Concentrations of 0.1 N HCl extractable P were drastically increased in the soil surface and in some years to depths of 30 to 46 cm. However, extractable levels have little meaning at such high levels because, as will be seen later, such high levels can not be used to predict levels in plant tissues. No indication was found that sludge applications affected either total or 0.1 N HCl extractable levels of K in the soil to any depth less than 76 cm. Like K, total Na concentrations were not affected, at any soil depth, by sludge applications. But unlike K, concentrations of 0.1 N HCl extractable Na were significantly higher at all soil depths in sludge-treated plots. Neither total nor 0.1 N HCl extractable concentrations of either Ca or Mg were affected by sludge treatments at any soil depth. Because both Fe and Mn concentrations are naturally relatively high in soils, it was expected that sludge applications would not affect total concentrations. Concentrations of 0.1 N HCl extractable Fe and Mn tended to be increased by sludge applications to depths of 30 to 46 cm. Levels of extractable Fe and Mn in soil were highly variable from year to year and may have been due to weather conditions prior to sampling and length of storage before analysis of samples. Both total and 0.1 N HCl extractable concentrations of Zn were significantly increased in soil by sludge applications. In control plots total Zn concentrations were higher in the 61 to 76 cm soil depth than in more shallow sampling depths. At the deepest sampling depth sludge applications had not affected total Zn concentrations. But during the last 3 years of the study, total Zn concentrations were significantly higher in the 30 to 46 cm soil depth as a result of maximum-sludge-treatments. These results suggest that there has been some movement of Zn below the depth of sludge incorporation by plowing. Like Zn, total and 0.1 N HCl extractable Cd concentrations in the

(continued on Page 276)

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TABLE 12. AVERAGE CONTENTS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS OF SLUDGE APPLIED ON THE MAXIMUM-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO CORN.a/

Year	Solids	Total N	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb
						Annual means of sludge constituents									
	%					(ppm wet wt.)									
1969	1.91	1121				626	322	844	5	185	6.8	34	10.0	95	26
1970	2.31	1272				560	390	1210	7	181	8.9	43	8.7	112	41
1971	3.38	1566	1060	275	112	1056	316	1583	9	159	7.6	38	9.4	93	43
1972	1.98	858	565	117	107	974	260	827	10	78	3.2	12	1.5	24	18
1973	2.23	1093	683	134	132	1309	251	858	13	78	2.6	13	2.6	26	17
1974	2.75	1791	1070	139	127	776	300	1326	17	133	7.6	43	8.2	75	26
1975	2.57	1614	832	172	108	810	347	1375	16	111	5.6	35	9.2	75	27
1976	3.04	1927	1049	169	106	877	367	1431	18	122	8.4	48	14.3	98	29
1977	3.44	2096		118	44	937	410	1025	18	166	9.1	49	15.9	105	32
						Amounts of sludge constituents applied									
						kg/ha (dry wt.)									
1968b/		1920	1300			1073	553	1447	9	317	11	58	17	164	45
1969		2847	1928b/			1590	818	2140	13	470	17	86	25	242	66
1970		2908	1969b/			1280	892	2766	16	414	20	98	20	256	94
1971		5966	4031	1277c/	427	4023	1205	6031	35	605	29	146	36	355	163
1972		1090	718	148	136	1237	330	1050	12	99	4	16	2	31	23
1973		3054	1908	374	369	3657	701	2397	36	217	7	35	7	73	47
1974		3184	1902	247	226	1380	533	2358	30	236	13	76	14	134	47
1975		2050	1057	218	137	1029	441	1746	20	141	7	44	12	95	34
1976		3426	1863	300	188	1557	652	2541	32	217	16	85	25	174	51
1977		3191		180	70	1427	624	1561	27	253	14	75	24	160	49

a/ Appropriately smaller amounts of sludge from the same batch were applied on other sludge-treated plots on the same day.

b/ Estimated values.

c/ From 4-year report.

TABLE 13. CONCENTRATIONS OF TOTAL AND 0.1 N HCl EXTRACTABLE MACRO- AND TRACE-ELEMENTS, ORGANIC-C, AND pH DETERMINED FROM SOIL SAMPLES COLLECTED AT DEPTHS OF 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 cm IN BLOUNT SILT LOAM PLOTS.a/b/c/

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			%									
			Total N					Organic-C				
N & C	0-15	1971	0.11	0.12	0.13	0.16	0.03*	1.34	1.50	1.62	1.94	0.39**
		1972	0.11	0.14	0.18	0.22	0.04**	1.37	1.64	2.04	2.51	0.44**
		1973	0.11	0.14	0.16	0.20	0.03**	1.30	1.56	1.78	2.32	0.28**
		1974	0.14	0.14	0.18	0.28	0.05**	1.48	1.74	2.08	3.15	0.67**
		1975	0.13	0.17	0.20	0.31	0.03**	1.34	1.85	2.29	3.38	0.53**
		1976	0.14	0.14	0.18	0.23	0.06**	1.69	1.77	2.28	2.83	0.69**
		1977	0.11	0.15	0.21	0.27	0.09**	1.34	1.77	2.30	3.03	0.22**
	15-30	1974	0.09	0.10	0.12	0.12	0.02**	0.81	0.90	1.18	1.22	0.21**
		1975	0.07	0.09	0.11	0.15	0.02**	0.64	0.83	1.03	1.54	0.22**
		1976	0.09	0.10	0.12	0.14	0.03*	0.94	1.13	1.31	1.66	0.47**
		1977	0.08	0.10	0.12	0.15	0.05**	0.67	1.06	1.23	1.68	0.42**
	30-46	1971	0.05	0.06	0.06	0.06						
		1972	0.06	0.06	0.07	0.08						
		1973	0.06	0.06	0.06	0.05		0.48	0.40	0.37	0.38	
		1974	0.06	0.06	0.06	0.06		0.34	0.33	0.37	0.34	
		1975	0.06	0.05	0.06	0.05		0.35	0.34	0.40	0.37	
		1976	0.05	0.05	0.05	0.05		0.34	0.34	0.45	0.42	
		1977	0.06	0.06	0.06	0.06		0.48	0.51	0.52	0.53	
	61-76	1973	0.05	0.06	0.06	0.06						
		1974	0.06	0.07	0.06	0.06						
		1975	0.04	0.05	0.04	0.06						
		1976	0.05	0.05	0.06	0.05						
		1977	0.06	0.06	0.06	0.06		0.36	0.38	0.41	0.41	

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
P	0-15	1971	429	522	750	1152	512**	16	51	148	258	69**
		1972	723	1141	1540	2277	422**	80	284	759	1078	330**
		1973	635	1097	1350	2179	620**	82	276	519	1008	329**
		1974	890	1061	1480	3066	919**					
		1975	755	1465	2057	3801	848**					
		1976	780	1079	1810	2937	952**					
		1977	668	1102	2039	3200	136**					
	15-30	1974	387	568	853	999	379**	37	126	360	427	214**
		1975	304	452	718	1444	235**					
		1976	462	705	988	1457	311**					
		1977	399	621	942	1607	506**					
	30-46	1971	340	409	403	423	52**	15	25	27	31	9**
		1972	419	389	488	379		37	53	104	172	86**
		1973	506	514	493	512		18	24	19	26	
		1974	289	306	307	296		23	25	28	28	
		1975	257	259	268	296	30**					
		1976	269	261	311	284						
		1977	348	360	383	334						
	61-76	1973	636	646	626	607		31	34	35	26	
		1974	394	401	402	396		32	35	37	34	
		1975	308	304	298	268						
		1976	328	330	339	343						
		1977	297	354	311	308						

(continued)

TABLE 13. (continued)

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			---%---					---ppm---				
			Total					0.1 N HCl Extr.				
K	0-15	1971	1.80	1.91	1.78	1.82		222	224	229	268	
		1972	1.68	1.67	1.67	1.61						
		1973	1.71	1.73	1.72	1.67		215	298	265	253	
		1974	1.78	1.71	1.78	1.78		291	288	309	393	
		1975	1.83	1.81	1.86	1.74						
		1976	1.83	1.88	1.83	1.77						
		1977	1.92	1.87	1.85	1.84						
	15-30	1974	1.72	1.72	1.73	1.72		269	184	212	252	
		1975	1.75	1.72	1.74	1.68						
		1976	1.87	1.88	1.89	1.83						
		1977	1.90	1.88	1.89	1.84						
	30-46	1971	1.83	1.81	1.86	1.74		283	258	272	247	
		1972	1.78	1.77	1.70	1.70						
		1973	2.07	1.91	1.97	1.90		378	358	406	327	
		1974	1.80	1.77	1.78	1.79		264	233	260	264	
		1975	1.94	1.77	1.86	1.81						
		1976	1.82	1.89	2.01	1.83						
		1977	2.17	2.01	2.05	2.00						
	61-76	1973	2.31	2.44	2.30	2.32		248	304	279	310	
		1974	2.16	2.18	2.25	2.01		328	343	384	338	
		1975	2.31	2.27	2.48	2.39						
		1976	2.67	2.56	2.71	2.57						
		1977	2.60	2.60	2.55	2.66						

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			%					ppm				
			Total					0.1 N HCl Extr.				
Na	0-15	1971	0.59	0.61	0.59	0.60		13.7	24.0	26.8	32.0	6.2**
		1972	0.83	0.82	0.80	0.82		9.5	26.5	31.2	53.8	10.9**
		1973	0.79	0.78	0.78	0.78		27.5	45.5	35.8	36.2	
		1974	0.77	0.74	0.73	0.71		22.5	33.5	36.2	47.5	
		1975	0.65	0.66	0.62	0.66						
		1976	0.82	0.82	0.81	0.80						
		1977	0.79	0.75	0.76	0.77						
	15-30	1974	0.71	0.71	0.73	0.70		32.5	44.5	44.8	56.5	14.9*
		1975	0.73	0.74	0.77	0.78						
		1976	0.76	0.79	0.76	0.76						
		1977	0.57	0.61	0.66	0.60						
	30-46	1971	0.65	0.66	0.62	0.66		17.8	27.0	38.2	52.5	5.1**
		1972	0.67	0.71	0.68	0.73		13.2	33.0	38.8	56.0	9.3**
		1973	0.52	0.59	0.53	0.56		46.2	57.5	67.8	67.5	13.0*
		1974	0.40	0.43	0.45	0.42		25.8	41.0	48.2	57.2	10.9**
		1975	0.57	0.61	0.61	0.69						
		1976	0.52	0.57	0.55	0.59						
		1977	0.59	0.62	0.59	0.63						
	61-76	1973	0.38	0.48	0.38	0.42	0.07**	69.0	68.8	81.2	91.0	18.0**
		1974	0.35	0.38	0.35	0.34		66.0	69.0	84.5	93.2	16.7**
		1975	0.36	0.51	0.45	0.54						
		1976	0.50	0.50	0.46	0.51						
		1977	0.48	0.52	0.46	0.51						

(continued)

TABLE 13. (continued)

Parameter	Depth cm	Year	Total: 0	Total: 1/4 Max	Total: 1/2 Max	Total: Max	Total: LSD	0.1 N HCl Extr.: 0	0.1 N HCl Extr.: 1/4 Max	0.1 N HCl Extr.: 1/2 Max	0.1 N HCl Extr.: Max	0.1 N HCl Extr.: LSD
			%	%	%	%	%	%	%	%	%	%
Ca	0–15	1971	0.30	0.36	0.32	0.31		0.16	0.15	0.16	0.17	
		1972	0.25	0.28	0.25	0.29		0.11	0.16	0.15	0.16	
		1973	0.34	0.46	0.43	0.40		0.17	0.26	0.23	0.23	
		1974	0.72	0.71	0.61	0.81		0.28	0.53	0.27	0.39	
		1975	0.52	0.73	0.67	0.83						
		1976	0.64	0.68	0.71	0.80						
		1977	0.59	0.65	0.64	0.71						
	15–30	1974	0.26	0.27	0.27	0.25		0.13	0.12	0.13	0.12	
		1975	0.38	0.62	0.46	0.47						
		1976	0.51	0.54	0.55	0.59						
		1977	0.34	0.41	0.43	0.49						
	30–46	1971	0.28	0.21	0.18	0.25		0.16	0.15	0.16	0.17	
		1972	0.18	0.19	0.18	0.20		0.09	0.09	0.10	0.10	
		1973	0.25	0.20	0.21	0.25		0.17	0.13	0.13	0.14	
		1974	0.22	0.36	0.32	0.22		0.11	0.25	0.12	0.11	
		1975	0.30	0.39	0.30	0.34						
		1976	0.36	0.36	0.37	0.35						
		1977	0.36	0.41	0.43	0.49						
	61–76	1973	1.08	0.71	0.97	0.72		1.28	0.94	1.32	0.79	
		1974	0.46	0.30	0.35	0.29		0.76	0.38	0.43	0.48	
		1975	0.97	0.42	0.53	0.41	0.43*					
		1976	0.91	0.59	0.91	0.63						
		1977	1.38	0.91	0.99	0.97						

(continued)

TABLE 13. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			%									
			Total					0.1 N HCl Extr.				
Mg	0-15	1971	0.27	0.30	0.28	0.25		0.13	0.12	0.12	0.12	
		1972	0.25	0.25	0.23	0.24		0.05	0.07	0.05	0.05	
		1973	0.27	0.32	0.30	0.28		0.05	0.09	0.07	0.06	
		1974	0.34	0.32	0.29	0.30		0.09	0.06	0.09	0.10	
		1975	0.36	0.45	0.40	0.38						
		1976	0.43	0.43	0.44	0.42						
		1977	0.38	0.41	0.40	0.41						
	15-30	1974	0.32	0.32	0.29	0.28		0.06	0.06	0.05	0.04	
		1975	0.48	0.49	0.44	0.40						
		1976	0.53	0.51	0.50	0.49						
		1977	0.48	0.43	0.49	0.46						
	30-46	1971	0.56	0.41	0.38	0.37		0.13	0.12	0.12	0.12	
		1972	0.37	0.36	0.34	0.33		0.05	0.05	0.05	0.05	
		1973	0.55	0.34	0.46	0.48		0.09	0.06	0.06	0.07	
		1974	0.32	0.29	0.35	0.28		0.06	0.13	0.05	0.05	
		1975	0.62	0.59	0.58	0.56						
		1976	0.61	0.60	0.63	0.67						
		1977	0.72	0.73	0.72	0.68						
	61-76	1973	0.78	0.70	0.70	0.64		0.70	0.41	0.57	0.42	
		1974	0.61	0.49	0.44	0.56		0.33	0.28	0.28	0.26	
		1975	0.81	0.67	0.71	0.69						
		1976	1.07	1.10	1.03	0.84						
		1977	1.09	0.81	0.96	0.66						

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			%					ppm				
			Total					0.1 N HCl Extr.				
Fe	0–15	1971	1.83	1.85	1.80	1.85		499	536	792	775	
		1972	1.70	1.77	1.80	1.74		195	512	773	1320	337**
		1973	1.83	1.83	1.83	1.96		1136	1374	1643	2030	549**
		1974	2.30	2.20	2.00	2.00		688	831	1157	1762	379**
		1975	1.94	2.07	2.06	2.17						
		1976	1.93	1.85	1.95	2.14						
		1977	1.95	2.06	2.11	2.20	0.15*					
	15–30	1974	2.20	2.35	2.26	2.41		948	850	1020	1210	
		1975	2.51	2.22	2.19	2.04						
		1976	2.40	2.25	2.32	2.36						
		1977	2.98	2.23	2.81	2.73						
	30–46	1971	4.09	4.04	4.08	3.92		741	672	707	791	
		1972	2.99	2.76	2.75	2.61		364	427	507	628	171*
		1973	3.64	3.34	3.41	3.39		1372	1389	1528	1280	
		1974	4.41	3.95	4.14	3.70		710	666	655	663	
		1975	3.92	3.58	3.62	3.34						
		1976	3.98	3.68	3.71	3.84						
		1977	4.23	3.90	3.96	3.71						
	61–76	1973	3.70	3.68	3.67	3.67		716	1330	905	1192	
		1974	4.62	5.68	4.82	4.81		830	1046	1259	1007	
		1975	4.26	4.34	4.59	4.32						
		1976	4.62	4.15	4.28	4.38						
		1977	4.33	4.58	4.65	4.52						

(continued)

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TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Mn	0-15	1971	1253	1314	1378	1469		304	306	427	402	
		1972	1224	1262	1158	1174		139	231	313	454	156**
		1973	1163	1053	1188	1180		729	763	830	838	
		1974	2320	1696	1176	1663		800	788	966	917	
		1975	1787	1766	1757	1600						
		1976	1617	1291	1406	1535						
		1977	1249	1392	1335	1501						
	15-30	1974	936	1157	1023	962		424	538	573	581	
		1975	859	1096	1104	1213						
		1976	982	1138	1062	1093						
		1977	823	1029	1057	1098						
	30-46	1971	509	536	534	492		45	63	57	61	11**
		1972	614	555	628	609		36	55	95	119	31**
		1973	324	353	316	295		181	130	160	142	
		1974	426	515	458	461		106	156	115	122	
		1975	422	444	510	568						
		1976	417	428	449	405						
		1977	411	376	376	477						
	61-76	1973	524	587	502	436		344	365	354	289	
		1974	706	664	741	566		388	350	402	285	
		1975	745	670	783	642						
		1976	675	631	687	689						
		1977	644	664	669	661						

(continued)

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TABLE 13. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Zn	0-15	1971	72	110	163	260	73**	13	41	98	181	63**
		1972	62	137	199	329	67**	16	80	150	277	62**
		1973	73	162	238	360	67**	13	81	118	244	65**
		1974	78	173	264	460	131**	20	83	157	341	105**
		1975	66	196	310	533	95**					
		1976	82	159	264	434	127**					
		1977	74	181	319	512	58**					
	15-30	1974	63	101	163	203	79**	6	32	79	111	54**
		1975	67	107	160	273	20**					
		1976	69	112	179	258	43**					
		1977	73	118	167	273	57**					
	30-46	1971	85	92	102	108	14**	8	12	16	18	4**
		1972	94	87	117	119		10	16	36	63	23**
		1973	102	97	102	109	8*	10	9	11	14	3**
		1974	85	79	86	97		5	5	7	13	4**
		1975	94	83	95	106	15**					
		1976	82	80	94	106	16**					
		1977	91	86	96	111	15*					
	61-76	1973	114	118	119	118		10	14	13	14	
		1974	105	107	110	108		7	9	10	10	
		1975	106	105	110	111						
		1976	103	103	112	109						
		1977	111	112	110	115						

(continued)

0.9

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Cd	0-15	1971	0.3	2.1	4.1	7.5	5.0**	<0.25	1.3	3.6	6.8	4.0**
		1972	0.5	3.8	7.0	13.6	3.9**	0.3	3.1	5.7	12.1	3.3**
		1973	0.7	4.7	7.9	13.2	3.6**	0.4	3.3	6.7	12.9	3.6**
		1974	0.9	3.6	7.0	15.6	4.5**	0.6	3.8	7.3	16.4	4.9**
		1975	0.5	7.1	12.6	24.5	5.3**					
		1976	0.7	4.6	9.9	19.4	6.4**					
		1977	0.6	7.0	13.4	24.7	4.6**					
	15-30	1974	<0.25	1.4	5.1	10.8	6.7**	<0.10	1.56	4.40	7.24	6.09**
		1975	<0.25	2.0	4.0	11.3	2.8**					
		1976	<0.25	2.3	5.1	10.0	2.1**					
		1977	<0.25	2.6	5.0	11.2	3.3**					
	30-46	1971	<0.25	<0.25	0.30	0.42		0.48	0.55	0.69	0.75	0.17*
		1972	<0.25	<0.25	0.52	1.51	0.65**	<0.10	0.32	0.71	1.87	1.09**
		1973	<0.25	<0.25	<0.25	<0.25		0.47	0.15	0.23	0.41	0.21*
		1974	<0.25	<0.25	<0.25	<0.25		<0.10	0.22	<0.10	0.29	
		1975	<0.25	<0.25	<0.25	<0.25						
		1976	<0.25	<0.25	0.26	0.57						
		1977	<0.25	<0.25	0.30	0.62						
	61-76	1973	<0.25	<0.25	<0.25	<0.25		0.19	0.12	0.14	0.30	
		1974	<0.25	<0.25	<0.25	<0.25		<0.10	0.16	<0.10	<0.10	
		1975	<0.25	<0.25	<0.25	<0.25						
		1976	<0.25	<0.25	<0.25	<0.25						
		1977	<0.25	<0.25	<0.25	0.28						

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Cu	0-15	1971	19	22	34	52	27**	3.9	8.4	19	32	19**
		1972	16	35	51	97	20**	3.9	18	33	71	11**
		1973	16	34	50	88	19**	5.4	19	31	55	17**
		1974	23	46	66	100	16**	8.4	24	39	86	22**
		1975	11	46	75	144	31**					
		1976	18	41	72	123	33**					
		1977	14	48	87	146	16**					
	15-30	1974	17	28	42	52	21**	3.6	11	22	29	16**
		1975	16	23	39	71	16**					
		1976	19	31	46	69	13**					
		1977	19	31	45	80	17**					
	30-46	1971	23	25	25	26		3.5	4.9	5.9	6.4	1.7**
		1972	36	34	43	32		7.0	7.3	7.8	13.0	
		1973	29	27	28	27		4.8	5.3	5.8	5.2	
		1974	28	27	27	26		3.7	3.6	4.1	4.1	
		1975	27	23	24	23						
		1976	28	26	27	25						
		1977	30	27	28	26						
	61-76	1973	35	37	34	34		3.4	5.2	4.0	4.4	
		1974	40	41	43	40		3.5	4.4	5.4	5.2	
		1975	37	36	37	34						
		1976	39	35	38	38						
		1977	39	39	38	38						

(continued)

TABLE 13. (continued)

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Ni	0-15	1971	10	17	12	15		2.3	3.5	5.3	7.0	2.0**
		1972	14	20	23	33	6**	2.5	5.0	7.3	13.6	2.2**
		1973	18	17	19	27		3.2	5.2	7.6	10.6	2.8**
		1974	10	13	15	21	5**	2.8	4.1	6.2	10.3	2.4**
		1975	14	22	25	36	6**					
		1976	17	22	28	37	8**					
		1977	17	23	31	44	6**					
	15-30	1974	22	25	25	33		0.5	2.1	3.3	4.4	2.8**
		1975	18	18	19	24						
		1976	20	21	25	28	5**					
		1977	22	22	26	31	5**					
	30-46	1971	30	30	30	29		2.0	3.0	3.0	3.0	
		1972	27	22	26	21		1.9	1.5	2.0	2.8	
		1973	30	17	21	22		1.7	1.9	1.4	2.0	
		1974	15	11	13	12		0.2	0.6	0.9	0.6	
		1975	27	22	25	21						
		1976	24	22	21	22						
		1977	35	28	31	28						
	61-76	1973	47	53	47	42		9.4	9.4	8.4	7.1	
		1974	34	35	40	32		6.8	6.3	7.8	4.7	
		1975	57	47	53	47						
		1976	47	44	55	47						
		1977	52	53	58	54						

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Cr	0-15	1971	29	43	61	86	5*	0.94	3.34	10.9	18.7	10.4*
		1972	27	60	86	151	47**	0.65	7.74	13.3	35.0	12.1**
		1973	36	74	88	139	24**	2.48	13.20	23.8	55.5	19.3**
		1974	39	54	92	200	72**	1.10	9.87	21.0	62.2	21.1**
		1975	37	94	138	222	91**					
		1976	38	77	129	228	79**					
		1977	37	95	163	283	43**					
	15-30	1974	28	42	65	74	27**	2.34	3.78	11.2	15.0	10.1*
		1975	42	53	70	120	24**					
		1976	41	61	84	126	33**					
		1977	43	63	87	147	31**					
	30-46	1971	54	51	57	60		0.64	0.82	1.28	1.55	0.55**
		1972	46	48	49	60	9**	0.45	0.72	1.60	3.43	1.97**
		1973	56	49	52	53		2.19	2.27	2.20	2.20	
		1974	46	44	48	46		0.97	0.97	0.77	0.77	
		1975	52	51	54	48						
		1976	49	48	50	48						
		1977	48	46	47	47						
	61-76	1973	55	55	58	52		2.35	2.81	2.34	2.58	
		1974	48	51	51	48		2.90	2.88	2.38	2.20	
		1975	58	55	60	58						
		1976	58	64	66	58						
		1977	62	54	62	60						

(continued)

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TABLE 13. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			ppm									
			Total					0.1 N HCl Extr.				
Pb	0-15	1971	31	39	44	60	5*	6.6	11.5	17.2	30.2	17.4**
		1972	32	53	72	101	25**	3.5	12.8	23.1	39.8	8.8**
		1973	30	44	59	91	19**	10.3	20.4	31.2	51.7	23.4**
		1974	31	42	56	110	42**	10.5	16.9	27.8	53.5	12.0**
		1975	30	59	88	155	31**					
		1976	38	56	82	131	41**					
		1977	34	57	90	139	15**					
	15-30	1974	21	29	38	41	12*	6.9	10.3	17.8	21.0	8.5*
		1975	24	31	44	66	11**					
		1976	23	36	44	66	17**					
		1977	30	36	49	77	24**					
	30-46	1971	28	29	32	28		2.1	2.7	4.2	5.3	2.2*
		1972	30	29	34	41	9*	3.3	4.2	7.4	10.4	4.8**
		1973	26	24	26	26		8.7	7.9	6.7	8.2	
		1974	21	19	21	20		5.6	5.5	5.0	5.2	
		1975	26	28	26	27						
		1976	29	31	31	30						
		1977	25	23	25	26						
	61-76	1973	24	23	26	25		8.0	8.8	7.2	6.8	
		1974	23	23	22	22		5.4	6.1	7.4	5.8	
		1975	25	29	27	27						
		1976	32	30	31	32						
		1977	24	26	23	23						

(continued)

TABLE 13. (continued)

			Sludge application rates									
Parameter	Depth cm	Year	0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			--------------Units----------------									
pH	0-15	1971	5.4	5.8	5.4	5.2						
		1972	5.6	5.7	5.2	5.0						
		1973	5.6	5.8	5.6	5.3						
		1974	6.3	6.8	6.4	6.2						
		1975	7.1	7.2	6.8	6.6						
		1976	7.0	7.0	6.8	6.4	0.4*					
		1977	6.4	6.5	6.1	6.0						
	15-30	1974	5.2	5.2	5.3	5.0						
		1975	6.1	6.4	6.0	5.8						
		1976	5.9	6.2	6.0	5.7						
		1977	4.6	5.2	4.9	5.0						
	30-46	1972	4.2	4.3	4.1	4.1						
		1973	4.2	4.0	4.0	3.8						
		1974	4.5	4.7	4.4	4.3						
		1975	4.3	4.5	4.2	4.0						
		1976	4.8	4.6	4.7	4.4						
		1977										
	61-76	1973	7.2	6.7	7.0	6.7						
		1974	6.7	5.8	6.2	5.9						
		1975	7.0	5.4	6.0	5.3	1.0*					
		1976	7.2	7.2	7.1	6.1	0.8*					
		1977	7.0	5.9	6.4	5.8						

a/ Concentrations are on a dry weight basis.

b/ Digested sludge was applied annually on replicated plots at various rates and control or check plots were annually treated with a relatively high rate of inorganic fertilizer.

c/ Samples were collected from plots identified as the NW 800 series.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

0 to 15 and 15 to 30 cm depths of soil were increased by sludge applications. It is not certain that concentrations of Cd were increased in the 30 to 46 cm depth of soil by sludge applications, because results were highly variable from year to year. Concentrations of total and 0.1 N HCl extractable Cu, Ni, Cr, and Pb were increased in the 0 to 30 cm depth of soil by sludge applications. During the early years of the study there was some indication that concentrations of some of these elements were increased in the 30 to 46 cm soil depth. But since significant differences were not observed in later years, after stainless steel tubes were used to collect samples, it seems unlikely that these metals were transported below the 30 cm soil depth.

At the beginning of the study the soil pH was about 5.6, but by 1970 it had decreased to a value of 4.9 in the surface of maximum-sludge-treated soil. In 1972 agricultural limestone was applied at rates calculated to increase soil pH to 6.5 in all plots. By 1975, soil pH values in the soil surface had increased to 6.6 in maximum-sludge-treated and to 7.1 in control plots. Then both decreased thereafter. Soil pH in 0 to 15 and 61 to 76 cm depths were decreased by sludge application in 1976, as was the case at the deeper depth in 1975.

Corn Yields--

Populations varied considerably from the planned 60,000 plants per hectare, as may be seen in Table 14. In 1974 plant populations exceeded intended levels as a result of an error and in 1977 populations were reduced by dry weather and high winds at the time plants were trying to establish brace roots. Grain yields may have been affected by plant populations during these 2 years (Table 14), but in 1974 the maturation of late planted corn was abruptly terminated by a killing frost on September 23rd. During the 10 year period, ½-maximum-and maximum-sludge treatments caused significant increases in corn yields only four times, but perhaps the most remarkable aspect of these data is that yields were never decreased by sludge applications. Maximum yields were generally obtained with the ½-maximum loading rate and while yields were never decreased, doubling this rate increased yields only in the unusual year of 1974 when maximum-treated plots had about 10,000 fewer plants than ½-maximum-treated plots. All sludge treatments resulted in significantly higher ten-year average grain yields than were produced with high rates of conventional inorganic fertilizers, but average yields from ½-maximum-and maximum-sludge-treated plots were not significantly different. Stover yields were significantly ($P \leq 0.05$) increased as a result of ½-maximum-and maximum-sludge applications during the last two years of the study. Plant populations were somewhat lower these two years than in former years. Yield responses to sludge applications were generally significant when rainfall was below normal levels in both months of July and August (Table 15). Although very little of the sludge-water actually infiltrated the soil surface, it no doubt did conserve soil moisture that would have otherwise been lost by evaporational processes.

Chemical Composition of Corn Plant Tissues--

Although corn growing on control plots was supplied with ample quantities of inorganic fertilizer, leaf-N concentrations were frequently increased by maximum sludge applications (Table 16). Maximum sludge applications increased N concentrations in grain and stover rather infrequently when compared to

(continued on Page 291)

TABLE 14. PLANT POPULATIONS AND CORN GRAIN AND STOVER YIELDS.

Year	Sludge application rates				
	0	1/4 Max	1/2 Max	Max	LSD
	Population 1,000 plants/ha				
1972	55.3	57.2	57.8	56.5	
1973	69.1	69.0	70.8	67.8	
1974	91.0	93.9	89.2	79.4	
1975	61.0	61.6	63.8	62.4	
1976	49.8	52.5	52.2	53.3	
1977	47.8	49.5	49.9	49.4	
	Grain yields mt/ha (15.5% moisture)				
1968	4.2	6.0	7.2	7.0	
1969	9.0	9.3	9.4	9.4	
1970	5.5	7.5	7.6	8.6	1.8**
1971	6.1	6.5	6.9	7.9	
1972	8.9	8.6	9.0	8.8	
1973	4.0	6.0	6.7	7.6	1.9**
1974	3.5	3.2	3.9	5.1	1.0**
1975	8.2	9.4	9.4	9.4	
1976	6.5	7.3	8.0	8.0	0.9**
1977	5.3	4.8	5.6	6.3	
Mean	6.1	6.9	7.4	7.8	0.7**
LSD	1.4**	1.7**	1.2**	1.0**	
	Stover yields mt/ha (dry weight)				
1972	5.9	6.2	6.6	6.3	
1973	7.9	9.3	10.5	10.3	
1974†					
1975	8.2	9.5	10.2	10.6	
1976	4.9	6.9	7.1	7.8	1.6*
1977	5.7	5.6	6.6	6.2	0.6*

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

† Missing Data

TABLE 15. AVERAGE RAINFALL AT THE NORTHEAST AGRONOMY RESEARCH CENTER DURING THE 10 GROWING SEASONS. THE 1941 TO 1970 MONTHLY AVERAGE RAINFALL FOR THE AREA IS PRESENTED FOR COMPARISON.

Year	Month						
	April	May	June	July	August	September	Totals
	Rainfall in cm						
1968	6.4	5.4	14.0	6.4	3.4	9.4	44.9
1969	9.1	13.0	17.9	15.7	1.8	3.2	60.7
1970	10.4	13.2	11.0	6.8	2.5	22.1	66.0
1971	1.5	6.7	4.2	7.0	5.0	5.5	29.8
1972	9.7	4.7	12.5	14.0	18.8	11.6	71.1
1973	16.4	10.8	9.5	3.3	3.2	9.9	53.1
1974	10.3	22.0	13.0	4.1	0.9	7.0	57.2
1975	10.0	10.5	12.2	6.0	0.9	3.2	50.8
1976	7.6	9.4	5.7	10.9	2.7	5.3	41.7
1977	3.6	3.8	10.5	4.2	14.0	25.9	62.0
1941-1970 Average	9.4	9.1	10.4	9.8	7.7	8.4	54.8

TABLE 16. CONCENTRATIONS OF MACRO- AND MINOR-ELEMENTS AND ASH WEIGHTS IN CORN LEAF, GRAIN, AND STOVER SAMPLES FROM BLOUNT SILT LOAM PLOTS.[a/][b/]

Constituent	Year	Sludge treatment 0	 1/4-Max	 1/2-Max	 Max	LSD
		Leaf %				
N	1970	2.01	2.22	2.10	2.44	
	1971	2.90	2.97	3.14	3.20	0.18*
	1972	3.01	3.02	3.06	3.29	0.22**
	1973	2.76	2.78	2.96	3.02	0.18**
	1974	3.01	2.96	3.21	3.28	0.21**
	1975	3.06	2.96	3.15	3.20	0.17**
	1976	2.75	2.55	2.78	2.81	
	1977	3.14	3.06	3.24	3.19	
		Grain %				
	1970	1.53	1.47	1.59	1.65	
	1971	1.67	1.84	1.92	2.24	0.30**
	1972	1.53	1.56	1.61	1.62	
	1973	1.68	1.62	1.71	1.66	
	1974	1.59	1.63	1.72	1.75	0.12*
	1975	1.47	1.40	1.51	1.49	
	1976	1.44	1.49	1.48	1.54	
	1977	1.90	1.87	1.90	1.72	
		Stover %				
	1972	0.86	0.96	0.97	1.06	
	1973	1.06	0.94	1.03	1.03	
	1974	1.04	1.07	1.28	1.64	0.40**
	1975	0.64	0.65	0.79	0.94	0.17**
	1976	0.91	0.83	1.14	1.18	
	1977	1.38	1.40	1.30	1.33	

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
				Leaf		
				%		
P	1970	0.27	0.29	0.29	0.33	0.04**
	1971	0.32	0.33	0.35	0.39	0.04**
	1972	0.28	0.28	0.32	0.35	0.04**
	1973	0.33	0.33	0.36	0.42	0.04**
	1974	0.40	0.37	0.38	0.42	0.03*
	1975	0.30	0.30	0.34	0.36	0.04**
	1976	0.39	0.38	0.43	0.45	0.05**
	1977	0.29	0.27	0.32	0.30	
				Grain		
				%		
	1970	0.50	0.46	0.49	0.56	
	1971	0.30	0.30	0.31	0.35	0.03*
	1972	0.28	0.27	0.32	0.34	0.05**
	1973	0.33	0.31	0.35	0.37	0.04*
	1974	0.28	0.29	0.32	0.37	0.07**
	1975	0.31	0.31	0.32	0.34	
	1976	0.36	0.32	0.34	0.40	
	1977	0.32	0.34	0.36	0.36	
				Stover		
				%		
	1972	0.05	0.06	0.10	0.19	0.05**
	1973	0.13	0.10	0.14	0.25	0.07**
	1974	0.08	0.10	0.11	0.18	0.06**
	1975	0.06	0.07	0.11	0.19	0.06**
	1976	0.08	0.08	0.13	0.19	0.04**
	1977	0.15	0.12	0.16	0.24	0.09**

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
				Leaf %		
K	1970	2.12	2.25	2.12	2.11	
	1971	1.63	1.52	1.74	1.73	
	1972	2.06	2.13	2.26	2.35	
	1973	2.60	2.64	2.77	2.73	
	1974	2.21	2.24	2.23	2.39	
	1975	3.16	3.14	3.38	3.31	0.17*
	1976	2.58	2.54	2.55	2.65	
	1977					
				Grain %		
	1970	0.44	0.45	0.47	0.51	
	1971	0.47	0.47	0.46	0.48	
	1972	0.26	0.27	0.30	0.33	0.04*
	1973	0.15	0.15	0.16	0.15	
	1974	0.35	0.36	0.37	0.38	
	1975	0.50	0.53	0.51	0.58	0.06*
	1976	0.44	0.40	0.42	0.43	
	1977					
				Stover %		
	1972	0.66	0.92	1.05	1.20	0.31**
	1973	1.32	1.30	1.50	1.76	0.28**
	1974	1.58	1.70	2.44	2.09	0.48*
	1975	1.98	2.06	2.01	2.36	
	1976	2.04	1.95	1.88	2.21	
	1977					
				Leaf ppm		
Na	1970	96	122	111	94	
	1971	38	72	55	72	23.4*
	1972	245	248	245	263	
	1973	294	301	315	308	
	1974	409	345	342	418	
	1975	112	105	136	105	
	1976	294	325	276	293	
	1977	26	38	31	33	

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
				Grain ppm		
Na	1971	2.5	1.5	1.8	1.8	
	1972	3.2	3.5	2.8	5.8	
	1973	2.8	3.8	3.2	3.5	
	1974	12.0	21.2	18.8	8.8	
	1975	10.7	7.6	10.8	7.3	
	1976	5.0	2.8	4.8	3.5	
	1977	3.4	6.2	2.9	1.8	
				Stover ppm		
	1972	24	30	32	32	
	1973	25	28	33	35	
	1974	53	54	61	58	
	1975	70	76	113	103	
	1976	36	32	37	35	
	1977	31	27	24	38	
				Leaf %		
Ca	1970	0.51	0.49	0.57	0.55	0.05*
	1971	0.36	0.37	0.40	0.50	0.06**
	1972	0.36	0.35	0.39	0.35	
	1973	0.61	0.58	0.65	0.55	
	1974	0.57	0.61	0.59	0.57	
	1975	0.57	0.53	0.55	0.49	
	1976	0.57	0.61	0.66	0.83	0.17**
	1977	0.71	0.73	0.84	1.09	0.22**
				Grain ppm		
	1970	42	31	19	44	
	1971	37	28	22	37	
	1972	18	16	21	18	
	1973	20	21	19	17	
	1974	30	28	26	22	
	1975	38	39	34	37	
	1976	14	13	14	16	2*
	1977	43	43	49	55	

(continued)

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TABLE 16. (continued)

Constituent	Year	0	1/4-Max	1/2-Max	Max	LSD
		Sludge treatment				
		Stover				
		%				
Ca	1972	0.20	0.22	0.27	0.24	0.05*
	1973	0.32	0.28	0.28	0.31	
	1974	0.40	0.33	0.42	0.39	
	1975	0.24	0.23	0.22	0.27	
	1976	0.51	0.48	0.64	0.64	0.14**
	1977	0.50	0.46	0.57	0.69	
		Leaf				
		%				
Mg	1970	0.30	0.25	0.27	0.18	0.05**
	1971	0.27	0.24	0.22	0.19	0.04**
	1972	0.23	0.20	0.18	0.14	0.02**
	1973	0.29	0.24	0.20	0.15	0.10**
	1974	0.41	0.36	0.30	0.29	0.07**
	1975	0.23	0.23	0.21	0.18	0.03**
	1976	0.23	0.24	0.19	0.20	0.03*
	1977	0.31	0.29	0.28	0.26	0.35**
		Grain				
		%				
	1970	0.26	0.23	0.25	0.26	
	1971	0.12	0.12	0.12	0.12	
	1972	0.10	0.09	0.10	0.10	
	1973	0.11	0.11	0.11	0.10	
	1974	0.10	0.10	0.11	0.11	
	1975	0.12	0.10	0.07	0.13	
	1976	0.13	0.13	0.12	0.13	
	1977	0.13	0.11	0.12	0.12	
		Stover				
		%				
	1972	0.13	0.12	0.09	0.09	0.02**
	1973	0.19	0.19	0.15	0.11	0.07**
	1974	0.41	0.36	0.33	0.26	0.07**
	1975	0.15	0.16	0.14	0.13	
	1976	0.30	0.27	0.24	0.22	
	1977	0.28	0.26	0.23	0.21	

(continued)

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TABLE 16. (continued)

Constituent	Year	Sludge treatment				
		0	1/4-Max	1/2-Max	Max	LSD
		Leaf				
		ppm				
Fe	1970	107	84	101	112	
	1971	98	93	98	90	
	1972	159	160	154	144	
	1973	126	118	124	118	
	1974	131	124	127	129	
	1975	110	108	116	110	
	1976	90	79	88	89	
	1977	114	102	100	101	10**
		Grain				
		ppm				
	1970	24	23	28	32	
	1971	36	33	34	36	
	1972	19	16	20	19	
	1973	30	30	32	35	
	1974	17	19	19	19	
	1975	16	20	21	25	
	1976	17	22	22	20	
	1977	20	23	28	29	
		Stover				
		ppm				
	1972	211	231	286	166	
	1973	90	99	82	61	
	1974	198	215	291	232	
	1975	46	46	42	68	
	1976	148	138	118	98	
	1977	122	112	79	96	
		Leaf				
		ppm				
Mn	1970	81	83	92	116	22*
	1971	59	57	79	151	36**
	1972	64	60	126	180	76**
	1973	64	40	44	54	14**
	1974	72	80	81	80	
	1975	46	32	30	27	11**
	1976	84	68	75	63	
	1977	117	83	115	166	52**

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
		Grain				
		ppm				
Mn	1970	6.0	5.2	5.7	6.4	n.s.
	1971	6.0	6.0	5.5	8.2	2.1**
	1972	3.4	2.4	3.1	4.6	0.8**
	1973	8.2	6.8	6.8	6.6	0.9**
	1974	5.9	5.8	5.9	5.6	
	1975	6.4	5.2	4.6	4.4	1.0**
	1976	7.7	5.7	5.3	5.8	1.3**
	1977	9.0	7.2	6.1	8.2	1.7*
		Stover				
		ppm				
	1972	35	38	47	72	23*
	1973	29	31	38	36	
	1974	59	56	75	81	16*
	1975	31	27	27	29	n.s.
	1976	73	66	65	63	n.s.
	1977	85	50	65	92	38*
		Leaf				
		ppm				
Zn	1970	58	85	138	212	82**
	1971	28	95	158	259	43**
	1972	56	139	253	381	136**
	1973	60	113	223	328	77**
	1974	59	122	193	293	104**
	1975	38	122	193	281	45**
	1976	66	177	300	391	81**
	1977	71	202	335	454	88**
		Grain				
		ppm				
	1970	32	40	50	65	15**
	1971	24	37	36	53	10**
	1972	22	29	40	50	13**
	1973	29	37	51	58	6**
	1974	28	37	46	56	7**
	1975	24	36	44	53	6**
	1976	33	42	54	62	9**
	1977	30	43	50	62	9**

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment				
		0	1/4-Max	1/2-Max	Max	LSD
				Stover		
				ppm		
Zn	1972	43	133	237	340	72**
	1973	39	94	193	337	60**
	1974	25	99	200	301	62**
	1975	26	87	185	275	73**
	1976	37	170	358	397	80**
	1977	42	195	303	432	140**
				Leaf		
				ppm		
Cd	1970	0.6	3.1	6.0	17.1	7.9**
	1971	0.5	4.9	11.8	25.4	7.3**
	1972	0.7	8.6	18.5	21.9	7.4**
	1973	0.8	3.5	12.0	22.1	5.7**
	1974	0.2	1.4	3.2	10.9	6.0**
	1975	0.6	5.0	6.8	13.5	5.5**
	1976	1.5	6.3	15.4	32.0	4.5**
	1977	0.8	11.2	32.3	47.1	9.9**
				Grain		
				ppm		
	1970	0.30	0.60	0.79	1.00	0.20**
	1971	0.14	0.70	0.65	0.92	0.40**
	1972	0.14	0.45	0.83	1.10	0.52**
	1973	0.08	0.15	0.35	0.61	0.06**
	1974	0.09	0.18	0.40	0.81	0.22**
	1975	0.06	0.17	0.28	0.51	0.08**
	1976	0.09	0.26	0.42	0.84	0.13**
	1977	0.07	0.25	0.60	0.92	0.22**
				Stover		
				ppm		
	1972	1.0	12.5	23.0	27.1	6.1**
	1973	0.5	2.5	8.6	29.3	4.7**
	1974	0.5	2.5	9.4	24.6	9.2**
	1975	0.4	4.0	11.9	23.5	4.8**
	1976	0.5	4.9	15.5	29.8	4.4**
	1977	1.0	11.2	27.3	52.7	12.6**

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
		Leaf				
		ppm				
Cu	1970	8.9	9.0	10.2	8.7	
	1971	10.4	9.2	9.5	5.6	
	1972	12.4	13.6	14.3	15.4	
	1973	7.4	7.8	6.6	7.2	
	1974	12.3	12.5	12.9	14.0	
	1975	8.9	10.5	11.6	12.5	1.3**
	1976	8.8	11.4	11.7	14.1	2.3**
	1977	9.0	11.8	11.5	13.9	1.5**
		Grain				
		ppm				
	1970	2.7	3.7	2.7	2.9	
	1971	2.4	2.6	2.2	2.0	0.4*
	1972	2.8	3.0	2.9	3.1	
	1973	2.4	2.6	2.6	2.0	
	1974	3.0	3.1	2.6	2.2	
	1975	2.1	2.1	2.2	2.0	
	1976	3.0	2.5	2.8	3.2	
	1977	2.0	2.2	2.1	2.4	
		Stover				
		ppm				
	1972	10.0	8.2	8.5	7.8	
	1973	2.3	2.3	3.7	3.0	
	1974	4.2	4.9	8.2	8.3	3.7**
	1975	3.9	6.5	4.9	5.5	
	1976	6.0	7.0	7.5	7.4	
	1977	5.4	5.3	7.6	9.2	2.7*
		Leaf				
		ppm				
Ni	1970	1.1	1.5	1.4	1.9	
	1971	0.1	0.5	0.9	1.2	
	1972	0.1	0.1	0.5	1.0	0.7**
	1973	2.1	1.5	0.3	1.6	
	1974	0.3	0.4	0.6	0.4	
	1975	0.1	0.2	0.2	0.1	
	1976	0.4	0.4	0.3	0.9	
	1977	0.2	0.8	0.6	1.4	0.3**

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	1/4-Max	1/2-Max	Max	LSD
				Grain		
		ppm				
Ni	1970	1.6	1.6	2.1	3.1	1.0*
	1971	0.7	1.2	1.4	4.0	1.7**
	1972	0.6	0.8	1.3	2.2	0.4**
	1973	1.2	0.9	1.3	1.7	0.4**
	1974	1.4	1.6	1.9	2.0	
	1975	3.3	3.2	6.9	5.9	
	1976	0.6	0.6	1.0	1.6	0.4**
	1977	0.5	0.4	0.7	2.0	0.9**
				Stover		
		ppm				
	1972	0.9	0.7	1.1	1.5	
	1973	0.2	0.2	0.2	0.9	0.6*
	1974	0.6	0.8	1.5	2.0	0.8*
	1975	0.5	0.4	0.6	0.3	
	1976	0.6	0.4	1.1	1.6	0.5**
	1977	0.9	0.7	1.6	1.9	0.9**
				Leaf		
		ppm				
Cr	1970	0.9	1.0	1.4	1.9	
	1971	1.2	1.6	1.3	1.2	
	1972	1.5	2.1	2.1	1.4	
	1973	1.5	1.2	1.1	1.2	
	1974	1.4	1.3	1.4	1.0	
	1975	1.6	1.4	1.7	1.6	
	1976	0.2	0.3	0.3	0.3	
	1977	0.5	0.5	0.5	0.6	
				Grain		
		ppm				
	1970	0.28	0.35	0.34	0.38	
	1971	0.50	0.49	0.48	0.37	
	1972	0.29	0.38	0.34	0.18	
	1973	0.12	0.14	0.17	0.14	
	1974	0.78	0.27	0.39	<0.13	
	1975	-	1.4	1.0	-	
	1976	0.15	<0.13	<0.13	<0.13	
	1977	1.2	1.2	0.7	1.0	

(continued)

TABLE 16. (continued)

Constituent	Year	Sludge treatment 0	 1/4-Max	 1/2-Max	 Max	 LSD
				Stover ppm		
Cr	1972	1.2	1.6	1.8	1.4	
	1973	1.0	1.2	1.2	1.5	0.3*
	1974	0.8	0.9	2.2	2.5	
	1975	1.6	1.4	1.5	1.4	
	1976	0.7	0.5	0.8	0.6	
	1977	1.2	1.3	1.6	1.2	
				Leaf ppm		
Pb	1970	1.9	1.5	1.6	1.6	
	1971	2.1	1.8	2.9	2.0	
	1972	5.0	4.6	4.6	5.1	
	1973	4.2	3.7	2.9	3.5	
	1974	2.6	2.0	2.0	2.1	
	1975	1.3	1.9	1.2	2.2	
	1976	1.2	1.9	1.4	1.4	
	1977	1.4	1.5	2.4	1.1	0.75*
				Grain ppm		
	1970	1.7	1.4	1.5	1.5	
	1971	1.5	1.0	1.8	1.8	
	1972	0.3	0.2	1.1	1.0	
	1973	1.3	0.8	1.1	1.8	
	1974	1.2	1.5	1.0	0.9	
	1975	0.5	0.9	1.0	3.3	1.89*
	1976	1.7	0.8	0.9	2.5	
	1977	0.9	0.6	1.0	0.9	
				Stover ppm		
	1972	5.3	4.3	3.7	4.6	
	1973	4.0	1.4	1.2	1.4	
	1974	2.4	2.0	3.3	3.6	
	1975	1.3	1.4	1.2	2.2	
	1976	3.6	5.5	6.0	3.3	
	1977	3.7	3.5	4.0	3.3	

(continued)

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TABLE 16. (continued)

Constituent	Year	0	1/4-Max	1/2-Max	Max	LSD
		Sludge treatment				
		Leaf (%)				
Ash	1971	6.34	6.40	7.18	8.46	0.54**
	1972	7.95	8.03	8.93	9.55	0.93**
	1973	8.64	9.75	10.76	11.44	1.59**
	1974	7.72	8.40	8.72	9.30	0.87*
	1975	9.61	11.13	11.13	11.53	0.48**
	1976	8.39	8.88	10.25	11.47	0.66**
		Grain (%)				
	1970	1.48	1.52	1.56		
	1971	1.16	1.15	1.24	1.35	0.10**
	1972	1.30	1.25	1.42	1.56	
	1973	1.24	1.31	1.38	1.34	
	1974	1.42	1.46	1.56	1.62	0.14**
	1975 †					
	1976	1.40	1.46	1.44	1.44	
		Stover (%)				
	1972	4.78	6.02	6.24	6.57	1.24**
	1973	5.68	6.31	6.46	7.40	0.81**
	1976	8.16	7.76	8.96	8.78	

a/ Concentrations are on a dry-weight basis.

b/ Samples were collected from plots identified as the NW 800 series.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

† Missing data.

levels in similar tissue from control plots. Even though maximum sludge applications supplied an average of about 3.0 mt/ha of N each year, there was no indication that plants grown on these plots accumulated excessive amounts of the element. Because about 30 to 50% of the total N supplied as a constituent of sludge was NH_4-N, relatively high amounts of N may have been lost by volatilization processes. But with such excesses of remaining N being incorporated into the soil each year, plants were expected to accumulate higher concentrations of N than were observed in leaves and stover. About the same thing can be said for the uptake of P with regard to excessive uptake of the element by corn. Even though maximum sludge applications supplied extremely large quantities of P to the soil there was no indication that excessive amounts were accumulated by corn plants. However, maximum sludge application did cause small, but significant, increases of P levels in leaves and stover each year and frequently in grain as well. Levels of P in corn tissues were always within normally expected ranges of concentrations for plants growing on fertile soils. Concentrations of K were significantly increased in corn plant tissues by ½-maximum and maximum sludge application during a few years. Because relatively large quantities of K were broadcast applied across all plots each year and sludge contained rather low concentrations, it had not been expected that levels would be affected in plant tissues. Sodium concentrations in plant tissues varied considerably from year to year. Only leaf tissues from sludge-treated plots in 1971 contained more Na than similar tissues from control plots. The higher sludge application rates occasionally caused increased Ca concentrations in corn leaf and stover tissues and once, in 1976, an increase was observed in grain. Maximum sludge applications consistently caused decreased Mg concentrations in corn leaf tissues, but not in grain. Decreased Mg concentrations with higher sludge application rates were frequently observed in corn stover. It may be seen in Table 13 that total Mg concentrations in the surface soil in control plots is only a little less than total Ca concentrations, but the sludge used in this study generally contained only about 25 to 50% as much Mg as Ca. Next to N, amounts of Fe supplied to soil as a constituent of sludge were higher than any other element. Nevertheless, Fe contents of corn plant tissues were not affected by sludge applications. In sharp contrast to Fe, only nominal amounts of Mn were added to the soil as a constituent of sludges. Concentrations of Mn in corn plant leaves and grain varied considerably with sludge applications, but not always in the same way. In some years Mn contents in corn plant tissues were apparently increased by sludge applications and in other years decreased concentrations were observed. When Mn contents in leaves were increased or decreased by sludge applications, concentrations of the element in grain seemed to be affected in a similar manner. Conditions affecting the availability of Mn in control soil for uptake by plants tended to be exasperated by sludge applications. That is, when Mn concentrations were low or high in plant tissues from control soil they were correspondingly lower or higher in plant tissues from sludge-amended soil. However, the magnitude of grain-Mn contents did not vary a great deal from year to year nor by treatment when compared to leaf concentrations.

Concentrations of Zn and Cd were the only elements consistently increased in all plant tissues by sludge applications. The highest concentrations of Zn and Cd in leaves and stover were observed during the last year of the study, but Zn and Cd concentrations in grain were not different during the last year from those observed in earlier years. The results in Table 16 indicate that both Zn and Cd contents of leaves were affected to the greatest extent by amounts of sludge-borne Zn and Cd incorporated into soils each year rather than accumulated soil concentrations. Zinc and Cd concentrations in grain appeared to be affected very little by accumulations of these metals in soils as a result of annual sludge applications. During the last 3 years of the study, sludge applications caused significant increases in leaf-Cu contents, but concentrations of Cu in grain were unaffected by sludge applications. Maximum sludge applications increased Cu levels in stover during the 1974 and 1977 growing season. Altogether, it appeared that significant accumulations of Cu in the soil surface by successive years of applying sludge had little affect on concentrations of the element in crop tissues. At maximum application rates, sludge-borne Ni occasionally increased concentrations of the element in corn leaves and stover. Concentrations of Ni were significantly increased in corn grain by maximum sludge applications each year, except in 1974. But as was the case with other elements, concentrations of Ni were not increased in corn plant tissues as a result of successive years of applying sludge. Concentrations of Cr and Pb were not increased in corn plant tissues by sludge applications. Apparently, the availability of sludge-borne Cr and Pb for uptake by plants was maintained at a very low level in the soil, because relatively high amounts were applied each year without affect.

During the periods in which such measurements were made, ½-maximum and maximum sludge applications caused significant increases in the ash contents of corn leaves. Ash contents were increased only two years each in grain and in stover. During the years 1974, 1975, and 1976, Si contents of corn leaves were increased about 40 to 50% by maximum sludge applications. Thus, the increase in Si concentration accounts for a relatively high proportion of the increase in ash content of leaves. During the same years, increased Si concentrations, attributable to sludge applications, were not observed in grain, although grain-ash contents were significantly increased in 1974 by maximum loading rates.

CONTINUOUS SOYBEANS ON PLOTS OF BLOUNT SILT LOAM

General Description

The main objective of the study was to determine how soil chemical changes produced by sludge applications affect soybean (*Glycine max* L.) nutrition and chemical composition of plant tissues.

Three replications of 12.2 X 12.2 m plots in a random complete block were established on Blount silt loam in the fall of 1968 for the following treatments of liquid sludge by depths of application: zero or control; maximum, or 25.4 mm; one-half maximum, or 12.7 mm; one-fourth maximum, or 6.4 mm application rates of sludge; and well water supplied at the same time and rate as maximum sludge applications. The plots were split and superphosphate

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was applied by broadcasting 118 kg/ha of P each year. All plots received a broadcast application of KCl to provide 224 kg/ha of K. After fertilizers were applied, plots were fall-plowed. In subsequent years all inorganic fertilizers were applied before spring plowing. Agricultural limestone was applied at rates estimated to maintain soil pH between 6.0 and 6.5. Immediately after the ridging and furrow operation, soybeans were planted on the ridges.

Except for a 1- or 2-day temporary storage period, digested sludge drawn directly from digesters at the Stickney or Calumet wastewater treatment plants (Chicago) was applied by furrow irrigation as often as weather conditions permitted. In most years the first sludge application was made when soybean seedlings were 10 to 12 cm tall. To maximize changes in the chemical and physical properties of soils in as short a time as possible, sludge applications were generally continued after harvest, for as long as weather conditions permitted rapid dewatering of sludge on the soil surface.

Sufficient quantities of digested sludge for one complete irrigation were temporarily stored in two buried tanks. Before being hauled to the field, the sludge was mixed by being pumped from one tank to the other. Samples of the digested sludge were collected at the beginning and end of a particular irrigation and composited for later analyses.

Six single soil core samples were collected annually between the spring plowing and ridging operation from each plot to a depth of 76 cm. The core samples were composited to provide representative samples from the 0 to 15 and 30 to 46 cm depths in each plot. In 1973 and 1974, additional samples from the 15 to 30 and 61 to 76 cm soil depths were collected from each plot. Soil samples were dried in a forced draft oven at 60°C and pulverized to pass a 60-mesh screen using a grinder equipped with tungsten-carbide faces.

After initiation of flowering, soybean leaves and petioles from the third and fourth positions from the top of 20 randomly selected plants in each plot were collected. Leaf and petiole samples were rinsed in deionized water and placed in sealed paper bags for transporting to the laboratory. To determine yields and collect grain samples whole soybean plants in a 5.03 m segment of each of the two center rows of each plot were hand harvested (cut off approximately two cm above the soil surface) and the seeds were separated in a small stationary thrasher. All plant tissue samples were dried at 60°C in a forced draft oven. Dried tissue samples were ground and stored in acid-cleaned sample bottles.

Sludge, soil, and plant tissues were analyzed by using the standard procedures discussed in Section I of this report. Fractionation of inorganic soil and sludge phosphates were performed according to the modified Chang and Jackson procedure as described by Peterson and Corey (1966).

Discussion of Results

Sludge Loading Rates--

Total annual and accumulative applications of digested sludge over the period of the study are shown in Table 17. The sludges contained from 1.0 to 4.3 percent solids and these data were used to calculate amounts of dry solids applied each year. Applications were made until the spring of 1972 by furrow irrigation as often as weather conditions and available labor permitted. In 1972, only one application had been made when the soybean seedlings on maximum-sludge-treated plots began to show symptoms of P toxicity. After severe P toxicity symptoms were observed, sludge applications were suspended until harvesting operations were completed in 1973. When P toxicity symptoms did not occur on soybeans growing on maximum-sludge-treated plots in 1973, it was decided that sludge applications would be resumed only on plots that in previous years had also received a broadcast application of superphosphate before plowing. This permitted further observation of conditions associated with P toxicity in soybeans simultaneously with changes in availability of residual sludge-borne P and trace elements to soybean plants. Concentrations in sludges of several essential and nonessential elements for plants are shown in Table 18 along with calculated average dry weight amounts of each element applied each year as a constituent of sludge.

Changes in Chemical Properties of Soil--

As shown in Table 19, accumulations of several elements in soil reflected the amounts added each year as a constituent of sludge. Organic-C contents were significantly increased in the surface (0-15 cm) of the soil each year and an accumulative effect was observed. Where maximum sludge applications were terminated after one application in 1972, soil organic-C contents in maximum-sludge-treated plots continued to be significantly higher throughout the six succeeding years. Apparently, the amount of sludge-borne organic-C that remained after the first year following termination of sludge applications was fairly resistant to further decompositional processes. Increases in soil contents of total N paralleled those of organic-C in that ½-maximum and maximum sludge applications significantly increased amounts in the soil surface and were decreased very little after terminating sludge applications. After the initial rapid increase in concentrations of organic-C and total N in the soil surface, further annual applications of sludge at approximately the same rates caused only slight increases in soil contents. Since only slight increases in organic-C and N were observed during the latter years from accumulative sludge applications it appears that an equilibrium between annual amounts of sludge-borne organic-C and N and decompositional losses of these elements would be established eventually. Neither organic-C nor N were increased in soil at depths below 15 cm. As expected, P concentrations were significantly increased in both the 0 to 15 and 15 to 30 cm depths of soil by annual sludge applications and concentrations tended to increase with successive years. Much of the increase in P contents in the 15 to 30 cm depth was probably due to incorporation of sludge below the 15 cm depth by plowing. There was no indication that P contents were changed at soil depths below 30 cm. The few significant differences in K and Na contents of soil were probably not caused by sludge applications. The few instances in which total Ca contents were significantly higher in the soil surface may have been caused by sludge applications because, relative to other elements, rather

(continued on Page 313)

TABLE 17. ANNUAL DIGESTED SLUDGE LOADING RATES, PERCENT SLUDGE SOLIDS, AND ACCUMULATED SOLIDS APPLIED ON MAXIMUM-SLUDGE-TREATED BLOUNT SILT LOAM PLOTS PLANTED TO SOYBEANS.

Year	Liquid sludge applied (cm)	Solids in sludge (%)	Dry solids applied (mt/ha)	
	Annual	Annual	Annual.	Accumul.
1969	20.3	1.78	42.76	42.76
1970	22.9	2.60	59.28	102.04
1971	33.0	3.36	134.88	236.92
1972	2.5	1.94	4.81	241.73
1973*	5.1	2.70	13.68	255.41
1974*	17.8	3.30	58.64	314.05
1975*	15.2	3.23	49.10	363.15
1976*	15.2	3.18	47.43	410.58

* Sludge applied to the P-amended plots only.

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TABLE 18. AVERAGE CONTENTS AND TOTAL ANNUAL AMOUNTS OF SEVERAL SLUDGE CONSTITUENTS APPLIED TO MAXIMUM-TREATED BLOUNT SILT LOAM SOYBEAN PLOTS.[a]

Year	Solids	Total N	NH_4-N	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cd	Cu	Ni	Cr	Pb
		Annual means of sludge constituents (ppm wet wt.)														
	%															
1969	1.78	980[b]	447[b]	556			472	233	515	4	132	5.8	26	7.6	85	17
1970	2.60	1282	582	812			665	429	1313	8	225	10.0	48	9.4	125	46
1971	3.36	1340	611[b]	962	260	115	1094	317	1479	9	152	7.2	36	9.3	90	42
1972	1.94	1370	658	578	91	110	916	227	705	10	87	3.7	16	0.5	21	21
1973	2.70	1444	629	952	160	120	1450	267	1233	16	98	5.2	27	7.4	45	23
1974	3.30	2047	932	1230	150	123	787	322	1387	19	155	8.8	49	9.9	83	34
1975	3.23	1808	828	984	244	109	977	430	1817	18	141	7.6	46	12.5	98	34
1976	3.18	2042	966	1043	159	98	857	365	1438	17	177	8.7	51	15.0	97	30
		Amounts of sludge constituents applied kg/ha (dry wt.)														
1969		1991[b]	908[b]	1130[b]			959	473	1046	8	268	11.8	53	15.4	173	34
1970		2931	1330	1856[b]			1520	981	3002	18	514	22.9	110	21.5	286	105
1971		4425	2018[b]	3176	858	380	3612	1562	4884	30	502	23.8	119	30.7	297	139
1972		348	167	147	23	28	233	58	179	3	22	0.9	4	0.1	5	5
1973		734	320	484	81	61	737	136	626	8	50	2.6	14	3.8	23	12
1974		3640	1657	2187	267	219	1399	572	2466	34	276	15.6	87	17.6	148	60
1975		2749	1259	1498	371	166	1239	654	2766	27	215	11.6	70	19.1	149	52
1976		3105	1469	1586	242	149	1303	555	2187	26	269	13.2	78	22.8	147	46

[a] Originally, all replicated plots were split for annual 0 and 118 kg P/ha applications. After 1973, P applications were terminated and sludge applications were continued after 1972 only on split-plots formerly treated with superphosphate. All sludge appliations were terminated after 1976, when plots were seeded to wheat.

[b] Estimated values.

TABLE 19. TOTAL CONTENTS OF SELECTED ELEMENTS AND pH DETERMINED IN 0 TO 15, 15 TO 30, 30 TO 46, and 61 TO 76 cm SOIL DEPTH SAMPLES FROM BLOUNT SILT LOAM PLOTS PLANTED TO SOYBEANS AND WHEAT.a/b/

			Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Org-C	0-15	1971	1.08	1.33	1.58	1.76	1.94	0.55**	1.05	1.38	1.47	1.76	2.11	0.64**
		1972	1.00	1.30	1.44	2.01	2.06	0.46**	0.99	1.34	1.59	1.93	2.46	0.62**
		1973	1.06	1.28	1.51	1.79	2.08	0.72**	0.99	1.34	1.50	1.66	2.10	0.66**
		1974	1.01	1.24	1.41	1.67	2.26	0.75**	0.98	1.30	1.43	1.72	2.01	0.70**
		1975	0.96	1.16	1.42	1.76	2.24	0.70**	0.87	1.27	1.39	1.55	1.93	0.61**
		1976	1.02	1.30	1.73	2.16	3.29	0.84**	0.94	1.33	1.46	1.55	2.09	0.66**
		1977	1.22	1.54	1.97	2.51	3.94	0.75**	0.82	1.27	1.34	1.42	1.86	0.47*
	15-30	1973	0.61	1.26	1.03	1.00	0.92		0.67	1.22	1.01	0.91	0.94	
		1974	0.64	1.17	1.04	1.02	0.87		0.64	1.33	1.11	1.14	1.00	
		1975	0.52	1.14	0.90	1.03	0.81		0.39	1.29	0.96	0.93	0.80	
		1976	0.57	1.15	1.03	1.10	1.08		0.59	1.27	1.13	1.12	0.98	
		1977	0.59	1.09	0.95	1.09	0.92		0.52	1.19	1.06	0.96	0.82	
	30-46													
		1973	0.37	0.82	0.42	0.40	0.42		0.46	1.40	0.82	0.68	0.46	
		1974	0.38	0.60	0.42	0.45	0.44		0.47	1.33	0.78	0.62	0.39	
		1975	0.33	0.66	0.36	0.39	0.38		0.43	1.42	0.78	0.76	0.37	
		1976	0.33	0.53	0.39	0.43	0.38		0.37	1.19	0.63	0.56	0.33	
		1977	0.38	0.71	0.45	0.44	0.37		0.42	1.37	0.78	0.63	0.38	

(continued)

TABLE 19. (continued)

			Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
N	0-15	1971	0.10	0.12	0.14	0.16	0.20	0.05**	0.11	0.12	0.14	0.16	0.23	0.07*
		1972	0.11	0.12	0.14	0.20	0.21	0.05**	0.10	0.13	0.16	0.19	0.29	0.07**
		1973	0.11	0.12	0.14	0.17	0.21	0.07**	0.10	0.13	0.14	0.16	0.19	0.05**
		1974	0.10	0.12	0.14	0.16	0.20	0.05**	0.10	0.13	0.13	0.16	0.19	0.05**
		1975	0.10	0.12	0.15	0.18	0.23	0.07**	0.10	0.13	0.14	0.16	0.20	0.05**
		1976	0.09	0.11	0.14	0.18	0.27	0.05**	0.09	0.12	0.14	0.15	0.20	0.05**
		1977	0.09	0.12	0.16	0.21	0.27	0.06**	0.09	0.11	0.14	0.15	0.20	0.07**
	15-30	1973	0.07	0.12	0.10	0.10	0.10		0.09	0.13	0.11	0.12	0.10	
		1974	0.12	0.12	0.12	0.12	0.11		0.10	0.13	0.11	0.12	0.12	
		1975	0.07	0.11	0.10	0.10	0.09		0.07	0.13	0.11	0.11	0.10	
		1976	0.06	0.10	0.09	0.10	0.10		0.07	0.11	0.10	0.11	0.09	
		1977	0.07	0.11	0.10	0.11	0.10		0.07	0.12	0.11	0.10	0.09	
	30-46	1971	0.05	0.07	0.06	0.06	0.06		0.06	0.09	0.11	0.11	0.06	
		1972	0.06	0.09	0.07	0.07	0.07		0.07	0.14	0.10	0.08	0.07	
		1973	0.05	0.09	0.06	0.06	0.06		0.06	0.14	0.07	0.08	0.07	
		1974	0.05	0.07	0.06	0.06	0.06		0.06	0.13	0.11	0.07	0.06	
		1975	0.06	0.09	0.06	0.07	0.07		0.07	0.15	0.10	0.10	0.06	
		1976	0.06	0.07	0.06	0.06	0.06		0.05	0.13	0.09	0.08	0.06	
		1977	0.07	0.08	0.07	0.07	0.07		0.07	0.14	0.10	0.08	0.07	
	61-76	1973	0.05	0.06	0.06	0.05	0.05		0.05	0.07	0.06	0.06	0.05	
		1974	0.05	0.05	0.06	0.05	0.05		0.05	0.06	0.06	0.05	0.05	
		1975	0.05	0.05	0.05	0.05	0.05		0.05	0.06	0.06	0.06	0.04	
		1976	0.05	0.04	0.05	0.05	0.05	0.004*	0.04	0.06	0.05	0.05	0.04	0.014*
		1977	0.04	0.06	0.06	0.06	0.06		0.06	0.08	0.06	0.06	0.06	

(continued)

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TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
P	0-15	1971	544	539	986	1440	1985	701**	460	539	783	1423	1864	419**
		1972	590	627	1305	2156	2494	538**	540	773	1152	1998	2994	443**
		1973	712	704	1238	1726	2395	994**	636	691	1283	1459	2365	293**
		1974	619	642	1027	1417	2777	675**	511	549	1180	1480	2075	957**
		1975	816	725	1330	1857	2902	835**	543	644	1201	1620	2291	256**
		1976	755	740	1243	1996	3738	1140**	586	597	992	1440	2257	743**
		1977	556	776	1784	2526	3145	257**	548	655	1069	1454	2409	434**
	15-30	1973	440	551	684	754	864	210*	479	614	745	751	771	
		1974	487	538	760	801	801	250*	478	574	731	850	898	277*
		1975	379	522	624	776	706		487	517	684	592	802	37*
		1976	457	545	762	819	871	240**	457	533	696	807	886	243*
		1977	508	553	718	838	932	290**	437	564	705	600	867	
	30-46	1971	517	503	539	497	550		545	699	575	532	588	
		1972	560	496	555	482	620		570	690	651	670	613	
		1973	471	493	513	467	491		529	722	641	550	511	
		1974	326	326	359	323	341		309	512	412	368	322	
		1975	360	447	414	357	384		282	618	526	475	303	
		1976	391	431	434	344	435		359	600	571	444	369	
		1977	478	432	473	420	489		435	588	641	476	413	
	61-76	1974	421	504	462	476	460		390	490	466	450	430	
		1975	296	376	330	359	312		264	388	313	380	277	
		1976	381	454	425	418	432		371	494	448	431	397	
		1977	429	439	456	435	451		390	509	453	449	438	

(continued)

TABLE 19. (continued)

			Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
K	0-15	1971	1.95	1.91	1.94	1.91	1.85		1.99	1.90	1.96	1.92	1.92	
		1972	1.86	1.79	1.74	1.77	1.81	0.06*	1.89	1.84	1.82	1.77	1.79	
		1973	1.79	1.77	1.73	1.76	1.74		1.85	1.76	1.80	1.75	1.75	
		1974	1.80	1.74	1.76	1.77	1.75		1.82	1.77	2.33	1.70	1.74	
		1975	1.89	1.86	1.84	1.85	1.79		1.96	1.86	1.89	1.83	1.85	
		1976	1.90	1.91	1.85	1.73	1.81		1.97	1.89	1.87	1.91	1.86	
		1977	1.95	1.93	1.78	1.83	1.87	0.11*	1.87	1.89	1.95	1.95	1.90	
	15-30	1973	1.93	1.83	1.84	1.86	1.84		2.09	1.81	2.03	1.83	2.04	
		1974	1.92	1.80	1.86	1.91	1.83		2.09	1.81	1.92	1.79	1.92	
		1975	2.04	1.91	1.97	1.92	1.92		2.79	1.89	2.31	1.90	1.96	
		1976	2.14	1.97	2.00	1.99	2.03		2.30	1.99	2.04	2.00	2.16	0.19*
		1977	2.10	1.92	2.01	2.00	1.98		2.25	1.97	2.01	1.92	2.06	0.20*
	30-46	1971	1.63	1.59	1.72	1.53	1.56		1.79	1.50	1.57	1.52	1.58	
		1972	2.04	1.88	1.91	1.87	2.18		2.26	1.96	1.97	1.92	2.11	
		1973	2.07	1.89	2.02	2.02	1.93		2.21	1.88	2.15	1.94	2.20	
		1974	2.06	1.84	1.94	1.83	1.84		1.97	1.80	1.97	1.89	2.10	
		1975	2.28	2.03	2.21	1.98	2.16		2.51	2.01	2.21	2.05	2.21	
		1976	2.41	2.03	2.21	2.07	2.15		2.43	2.00	2.13	2.09	2.30	
		1977	2.45	2.04	2.29	1.99	2.29		2.53	1.78	2.23	2.11	2.32	
	61-76	1973	2.37	1.90	1.90	2.03	2.09		2.03	1.97	2.13	2.10	2.09	
		1974	2.39	2.02	2.03	2.14	2.08		2.14	1.87	2.10	2.05	2.06	
		1975	2.67	2.06	2.02	2.26	2.12		2.44	2.01	2.37	2.34	2.37	
		1976	2.65	2.21	2.16	2.35	2.14	0.26*	2.63	2.13	2.38	2.36	2.43	
		1977	2.32	2.16	2.17	2.17	2.22		2.04	1.99	1.91	2.18	1.96	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Na	0-15	1971	0.81	0.81	0.80	0.81	0.77		0.76	0.82	0.78	0.78	0.75	
		1972	0.92	0.92	0.89	0.88	0.87		0.83	0.93	0.88	0.87	0.84	
		1973	0.88	0.89	0.87	0.84	0.84		0.82	0.90	0.85	0.86	0.80	
		1974	0.78	0.81	0.79	0.81	0.75		0.71	0.79	0.91	0.74	0.71	0.13**
		1975	0.88	0.88	0.85	0.83	0.83		0.82	0.87	0.85	0.85	0.81	
		1976	0.89	0.91	0.88	0.79	0.81	0.06*	0.82	0.92	0.87	0.87	0.82	
		1977	0.81	0.83	0.76	0.77	0.76		0.71	0.82	0.84	0.82	0.71	
	15-30	1973	0.77	0.87	0.82	0.84	0.78		0.68	0.85	0.76	0.79	0.75	
		1974	0.73	0.88	0.81	0.84	0.72		0.68	0.88	0.79	0.81	0.72	0.13*
		1975	0.75	0.91	0.87	0.83	0.75		0.65	0.89	0.83	0.80	0.76	
		1976	0.77	0.89	0.85	0.84	0.79		0.65	0.89	0.83	0.83	0.81	
		1977	0.71	0.82	0.81	0.81	0.76		0.62	0.87	0.76	0.79	0.73	
	30-46	1971	0.42	0.73	0.63	0.61	0.42		0.32	0.77	0.46	0.60	0.54	
		1972	0.67	0.85	0.77	0.78	0.74		0.65	0.88	0.77	0.82	0.69	
		1973	0.65	0.88	0.79	0.79	0.64		0.59	0.83	0.73	0.76	0.66	
		1974	0.59	0.72	0.72	0.62	0.62		0.48	0.80	0.67	0.69	0.55	
		1975	0.68	0.93	0.84	0.81	0.72		0.63	0.92	0.78	0.82	0.75	
		1976	0.67	0.89	0.79	0.78	0.71		0.57	0.86	0.79	0.78	0.72	
		1977	0.61	0.80	0.72	0.70	0.65		0.51	0.70	0.67	0.75	0.62	
	61-76	1973	0.51	0.70	0.51	0.59	0.50		0.41	0.71	0.52	0.61	0.37	
		1974	0.54	0.80	0.65	0.70	0.59		0.43	0.79	0.67	0.74	0.56	
		1975	0.57	0.77	0.62	0.71	0.62		0.43	0.78	0.60	0.72	0.61	
		1976	0.58	0.77	0.62	0.69	0.66		0.49	0.77	0.68	0.77	0.64	
		1977	0.43	0.66	0.56	0.59	0.53		0.41	0.70	0.49	0.61	0.46	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications H$_2$O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications H$_2$O	0	1/4 Max	1/2 Max	Max	LSD
			Sludge and water treatments											
									%					
Ca	0–15	1971	0.40	0.40	0.44	0.47	0.51	0.07**	0.39	0.41	0.43	0.46	0.52	0.08**
		1972	0.24	0.26	0.28	0.32	0.32		0.25	0.24	0.27	0.29	0.33	0.06**
		1973	0.41	0.43	0.47	0.47	0.49		0.42	0.39	0.45	0.45	0.53	
		1974	0.49	0.45	0.56	0.53	0.61		0.47	0.46	0.67	0.60	0.59	
		1975	0.42	0.39	0.41	0.42	0.41		0.52	0.38	0.45	0.44	0.46	
		1976	0.47	0.52	0.59	0.61	0.65		0.50	0.50	0.66	0.65	0.60	0.11*
		1977	0.46	0.48	0.59	0.53	0.70	0.12**	0.46	0.45	0.55	0.50	0.64	0.13*
	15–30	1973	0.33	0.27	0.35	0.32	0.33		0.29	0.35	0.34	0.35	0.33	
		1974	0.43	0.50	0.65	0.46	0.41		0.46	0.52	0.49	0.50	0.44	
		1975	0.36	0.40	0.40	0.44	0.37		0.35	0.42	0.40	0.37	0.38	
		1976	0.44	0.47	0.54	0.50	0.47		0.42	0.53	0.52	0.49	0.48	
		1977	0.39	0.42	0.49	0.46	0.47		0.41	0.47	0.45	0.44	0.46	
	30–46	1971	0.29	0.34	0.32	0.33	0.26		0.31	0.40	0.32	0.30	0.32	
		1972	0.21	0.22	0.20	0.23	0.20		0.28	0.25	0.23	0.21	0.21	
		1973	0.33	0.37	0.35	0.35	0.30		0.75	0.42	0.38	0.40	0.36	
		1974	0.40	0.39	0.37	0.40	0.43		0.51	0.44	0.42	0.41	0.41	
		1975	0.37	0.40	0.34	0.43	0.48		0.62	0.40	0.40	0.38	0.44	
		1976	0.32	0.39	0.37	0.40	0.41		0.68	0.52	0.50	0.46	0.48	0.14*
		1977	0.40	0.40	0.38	0.42	0.37		0.49	0.43	0.38	0.40	0.39	
	61–76	1973	1.02	0.32	0.82	0.37	0.69		0.81	0.32	0.88	0.31	0.14	
		1974	1.72	0.44	0.95	0.45	1.39		2.63	0.45	0.84	0.85	2.18	
		1975	1.35	0.43	1.29	0.75	1.14		3.04	0.45	1.22	0.56	1.79	
		1976	1.88	0.50	1.48	0.58	1.52		3.41	0.52	0.78	0.63	1.88	0.14*
		1977	1.70	0.41	1.12	0.58	1.26		2.41	0.44	1.09	0.56	2.04	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Mg	0-15	1971	0.43	0.40	0.41	0.43	0.45		0.53	0.40	0.44	0.44	0.49	
		1972	0.26	0.28	0.27	0.29	0.29		0.32	0.25	0.28	0.28	0.30	
		1973	0.36	0.38	0.34	0.34	0.37		0.44	0.31	0.38	0.36	0.40	
		1974	0.40	0.35	0.36	0.38	0.41		0.45	0.32	0.49	0.39	0.42	
		1975	0.43	0.39	0.41	0.42	0.47		0.52	0.38	0.45	0.44	0.46	
		1976	0.44	0.40	0.42	0.44	0.48		0.51	0.40	0.45	0.48	0.50	
		1977	0.43	0.39	0.44	0.40	0.48		0.50	0.37	0.46	0.41	0.50	
	15-30	1973	0.43	0.22	0.35	0.31	0.43		0.45	0.30	0.37	0.27	0.50	0.16**
		1974	0.60	0.39	0.54	0.47	0.51		0.71	0.40	0.43	0.55	0.56	0.16*
		1975	0.56	0.31	0.46	0.48	0.46		0.65	0.40	0.50	0.44	0.50	0.13*
		1976	0.43	0.32	0.37	0.36	0.49		0.55	0.33	0.38	0.39	0.44	
		1977	0.57	0.39	0.51	0.36	0.54		0.72	0.41	0.48	0.47	0.58	0.19*
	30-46	1971	0.54	0.38	0.51	0.47	0.43		0.51	0.38	0.49	0.40	0.47	
		1972	0.40	0.28	0.30	0.33	0.42	0.10*	0.52	0.23	0.34	0.33	0.41	0.17*
		1973	0.57	0.41	0.34	0.50	0.47		0.71	0.33	0.51	0.51	0.59	
		1974	0.71	0.39	0.52	0.54	0.68		0.75	0.36	0.53	0.54	0.71	
		1975	0.77	0.48	0.58	0.67	0.89		1.02	0.40	0.61	0.59	0.80	0.32*
		1976	0.76	0.40	0.58	0.62	0.73		0.89	0.38	0.55	0.61	0.76	
		1977	0.82	0.46	0.59	0.59	0.62		0.88	0.42	0.50	0.58	0.75	0.33**
	61-76	1973	0.84	0.46	0.56	0.46	0.61		0.88	0.46	0.74	0.65	0.90	
		1974	1.18	0.64	0.94	0.75	1.00		1.33	0.58	0.94	0.84	1.24	
		1975	1.20	0.69	1.11	0.94	1.14		1.45	0.66	1.16	0.86	1.11	
		1976	1.22	0.76	1.14	0.95	1.24		1.57	0.64	1.01	0.88	1.26	
		1977	1.20	0.71	1.07	0.84	1.15		1.49	0.59	1.00	0.78	1.59	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications H$_2$O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications H$_2$O	0	1/4 Max	1/2 Max	Max	LSD
			%											
Fe	0-15	1971	2.16	1.89	2.06	1.91	2.27	0.27**	2.48	2.03	2.11	2.18	2.27	0.28*
		1972	1.99	1.88	1.93	2.06	2.29		2.40	1.79	2.02	2.12	2.32	
		1973	2.11	1.87	1.99	2.16	2.21		2.47	1.88	2.21	2.04	2.39	0.41*
		1974	2.49	2.17	2.41	2.37	2.75	0.31**	2.79	2.10	2.90	2.39	2.74	
		1975	2.02	1.70	2.02	2.00	2.12	0.23*	2.42	1.72	2.08	1.94	2.13	0.42**
		1976	2.32	2.05	2.28	2.23	2.76	0.40*	2.58	2.01	2.19	2.38	2.51	
		1977	2.46	2.11	2.28	2.43	2.87	0.37*	2.49	2.06	2.46	2.43	2.75	
	15-30	1973	2.90	1.92	2.36	2.27	2.65		3.19	2.18	2.86	2.49	3.02	0.96*
		1974	3.19	1.94	2.75	2.32	2.77		3.45	1.96	2.54	2.39	2.89	
		1975	3.08	1.85	2.34	2.32	2.76		3.79	2.08	2.69	2.46	2.80	
		1976	3.21	1.88	2.53	2.42	2.92		3.37	1.95	2.36	2.27	2.82	
		1977	3.14	1.93	2.48	2.38	2.74		3.75	2.12	2.53	2.40	3.02	
	30-46	1971	3.84	2.35	3.37	2.99	3.98		4.09	2.46	3.65	2.98	3.54	
		1972	3.61	2.27	2.70	2.91	3.71		3.96	2.28	2.90	2.75	3.58	
		1973	3.68	2.26	3.13	3.04	3.60		3.98	2.45	3.24	3.08	3.68	
		1974	4.24	2.69	3.38	3.26	3.32		3.90	2.26	3.30	3.44	4.10	1.09*
		1975	3.95	2.39	2.95	3.49	4.72	1.46*	4.18	2.11	3.31	2.60	4.37	2.59**
		1976	3.85	2.67	2.95	3.18	3.60		3.85	2.27	3.21	3.14	3.92	
		1977	4.43	2.48	3.88	3.11	4.30		4.78	2.21	3.50	3.06	3.96	
	61-76	1973	3.80	3.41	2.40	3.73	3.90		3.55	3.31	3.72	3.83	3.76	
		1974	4.38	4.05	4.58	4.41	4.31		3.84	3.74	4.00	4.12	4.02	
		1975	4.04	3.44	3.69	4.04	3.77		3.86	3.26	3.87	3.76	3.54	
		1976	3.85	3.47	3.46	3.65	3.66		3.56	3.03	3.56	3.60	3.73	
		1977	3.71	3.69	3.82	3.94	4.10		3.50	3.12	3.24	3.72	3.24	

Sludge and water treatments

(continued)

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TABLE 19. (continued)

			Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
Mn	0-15	1971	1397	1316	1339	1450	1696		1089	1558	1288	1283	1270	
		1972	1103	1251	1395	1226	1270		978	1067	1100	1212	1017	
		1973	1349	1476	1484	1669	1390		1322	1575	1615	1340	1165	
		1974	1565	1730	1939	1715	1608		1415	1700	1858	1576	1410	
		1975	1683	1793	1981	1499	1608		1394	1646	1644	1382	1389	
		1976	1781	1889	2126	1736	1776		1336	1818	1770	1633	1496	
		1977	1665	1759	1967	1702	1545		1126	1939	1675	1401	1400	
	15-30	1973	850	1550	1451	1226	1114		874	1936	1837	1274	1061	
		1974	914	1680	1665	1391	1067		911	1901	1799	1399	893	
		1975	889	2007	1787	1177	1120		899	2054	1978	1245	977	
		1976	991	1743	1831	1340	1204		616	1902	1892	1437	1069	
		1977	901	1500	1603	1382	1094		835	1965	1751	1361	1016	
	30-46	1971	416	794	703	498	611		562	1214	1098	853	922	
		1972	634	910	867	593	683		651	1547	1280	791	705	
		1973	517	916	796	672	519		521	1857	1559	1012	653	
		1974	662	930	1197	721	833		617	2123	1511	1169	697	
		1975	475	1165	921	795	737		604	2157	1570	1300	621	
		1976	563	1321	1002	763	923		536	2139	1942	1147	670	
		1977	508	1041	927	734	652		624	2140	1461	964	582	
	61-76	1973	588	448	445	433	482		540	790	567	678	509	
		1974	646	476	474	576	528		554	1055	620	602	533	335**
		1975	550	468	472	604	454		645	976	681	700	503	
		1976	672	471	557	633	465		577	1116	646	682	564	
		1977	629	534	622	535	464		560	991	610	715	541	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
Zn	0–15	1971	46	50	147	235	337	134**	51	55	117	244	336	92**
		1972	56	69	136	266	350	64**	67	78	150	264	429	73**
		1973	79	81	174	263	346	84**	89	80	176	232	365	55**
		1974	64	69	136	203	370	94**	68	71	178	232	339	62**
		1975	60	71	158	249	385	69**	70	69	142	222	350	37**
		1976	51	62	180	281	542	80**	52	60	138	201	377	40**
		1977	66	77	213	339	481	115**	69	73	131	223	370	69**
	15–30	1973	88	71	104	146	181	43**	92	81	121	151	171	27**
		1974	65	54	80	117	140	46**	74	60	96	136	154	38**
		1975	76	67	84	135	152	35**	89	74	98	121	160	52**
		1976	67	60	100	128	187	28**	83	66	103	121	186	47**
		1977	75	67	100	142	182	48**	88	73	100	115	175	49**
	30–46	1971	86	57	84	81	86		92	71	85	72	89	15*
		1972	85	66	78	98	121	31*	94	83	86	84	117	23*
		1973	102	73	94	101	113		113	85	103	94	123	23**
		1974	87	56	78	85	96		87	70	84	76	98	16*
		1975	82	56	78	84	96		93	69	84	78	98	16*
		1976	96	55	76	95	109	29*	91	67	80	75	100	23**
		1977	92	78	81	80	112		101	94	77	87	100	
	61–76	1973	111	103	111	117	115		107	109	120	118	104	
		1974	99	85	96	110	97		86	89	100	94	89	8*
		1975	99	91	96	105	93		96	93	101	95	90	
		1976	92	85	88	99	91	8*	84	83	96	88	91	
		1977	96	94	97	100	92		95	86	103	95	95	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
Cd	0–15	1971	0.67	0.59	2.99	7.13	11.51	6.04**	0.59	0.73	2.34	6.74	11.19	5.02**
		1972	0.52	0.29	4.26	11.46	15.74	4.17**	<0.25	0.77	5.41	11.70	21.45	3.66**
		1973	0.42	0.46	4.98	11.90	16.23	6.25**	0.42	0.56	4.84	8.29	17.17	3.12**
		1974	<0.25	<0.25	3.96	7.57	16.77	5.10**	<0.25	<0.25	4.56	9.30	14.56	2.78**
		1975	<0.25	0.29	5.17	10.76	19.54	3.71**	<0.25	<0.25	4.61	9.12	16.72	2.81**
		1976	0.40	0.81	6.02	13.23	28.52	5.42**	0.30	0.76	4.16	7.96	17.46	3.05**
		1977	<0.25	0.77	8.95	16.90	33.70	5.08**	<0.25	0.74	4.72	8.51	19.19	4.47**
	15–30	1973	<0.25	0.74	1.68	4.04	5.13	2.43**	<0.25	0.78	2.52	3.29	3.80	2.04*
		1974	<0.25	<0.25	1.66	1.89	2.81	2.43*	<0.25	<0.25	1.44	2.96	3.67	2.25**
		1975	<0.25	<0.25	1.42	3.57	3.94	3.10**	<0.25	0.36	1.32	2.75	4.23	2.87**
		1976	<0.25	0.31	1.58	2.98	5.68	2.38**	<0.25	0.41	1.99	3.65	5.60	3.59**
		1977	<0.25	<0.25	1.34	4.44	5.21	2.34**	<0.25	<0.25	0.94	2.57	5.87	2.24**
	30–46	1971	0.39	<0.25	<0.25	0.44	0.52		0.39	0.44	0.55	0.68	0.52	
		1972	1.63	0.89	1.36	1.44	2.85		1.55	1.20	1.32	1.32	3.60	1.65*
		1973	1.57	0.94	1.56	1.23	1.65		1.45	1.09	1.60	1.49	1.52	
		1974	<0.25	<0.25	<0.25	<0.25	<0.25		1.56	1.63	2.06	1.83	2.02	
		1975	<0.25	<0.25	0.75	0.34	2.02	1.06*	<0.25	0.39	0.34	0.47	0.69	
		1976	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	
		1977	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	0.37	
	61–76	1973	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	
		1974	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	
		1975	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	
		1976	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	
		1977	<0.25	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	<0.25	

(continued)

TABLE 19. (continued)

			Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
Parameter	Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
Cu	0-15	1971	12	13	37	60	87	35**	13	15	28	65	90	27**
		1972	24	27	43	77	111	34**	24	28	46	79	132	40**
		1973	28	25	48	68	115	37**	29	20	41	56	104	19**
		1974	13	13	31	52	105	26**	16	13	50	61	98	24**
		1975	15	15	42	72	118	23*	18	14	37	61	101	11**
		1976	16	18	54	88	150	26**	18	19	36	57	109	13**
		1977	19	20	67	108	207	23**	20	18	38	62	114	19**
	15-30	1973	30	22	27	36	45	14*	29	24	33	35	41	
		1974	18	19	22	37	42	16*	21	19	23	32	42	15*
		1975	22	15	21	34	37	11**	28	16	24	30	43	9**
		1976	22	14	25	33	47	11**	27	16	27	33	50	19**
		1977	23	16	28	41	48	15**	30	19	28	32	55	14**
	30-46	1971	30	16	23	25	28		33	19	29	24	27	
		1972	35	21	29	37	44	13*	36	34	30	28	37	
		1973	32	25	30	28	31		35	22	27	28	33	
		1974	26	12	19	20	23		25	14	19	19	27	
		1975	29	18	25	26	26		34	18	26	24	29	10*
		1976	29	16	24	26	28		32	18	24	23	29	9*
		1977	33	19	27	27	30		36	20	28	24	34	11*
	61-76	1973	33	30	30	34	33		31	28	30	36	29	
		1974	32	27	29	31	30		34	22	29	29	29	
		1975	33	28	29	32	29		34	23	29	32	29	
		1976	32	28	28	32	30		32	21	28	30	31	
		1977	32	29	29	30	31		32	21	30	31	30	6*

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm											
Ni	0–15	1971	19	17	21	27	26		21	21	22	27	30	
		1972	18	23	28	33	39	13**	29	23	30	33	43	11**
		1973	14	14	19	24	28	8**	19	17	21	22	30	6**
		1974	21	19	26	29	35	6**	23	25	33	28	35	
		1975	17	21	24	27	42	16**	22	17	25	25	31	6**
		1976	19	19	27	30	51	6**	20	18	24	25	35	6**
		1977	21	20	32	43	63	9**	24	21	29	30	40	4**
	15–30	1973	21	18	17	16	22		30	17	26	20	29	
		1974	22	15	24	18	24		29	15	21	19	25	8*
		1975	22	19	20	20	25		30	24	25	21	24	
		1976	26	20	26	24	31	5*	33	21	29	24	31	
		1977	26	20	25	24	29		32	24	27	24	30	
	30–46	1971	27	11	21	18	25		37	17	25	19	27	
		1972	28	19	23	21	28		25	19	23	21	28	
		1973	23	10	20	14	23		29	16	27	17	31	
		1974	28	9	19	14	25		31	17	24	18	30	
		1975	32	19	26	20	29		44	25	32	25	32	
		1976	34	20	28	25	34		44	27	32	27	38	
		1977	38	23	31	25	33		48	31	40	30	38	
	61–76	1973	37	21	25	26	33		30	19	27	31	23	
		1974	39	23	28	31	31		31	21	29	28	28	
		1975	41	24	31	34	32		41	28	34	40	32	
		1976	46	27	34	36	35		44	27	37	42	38	
		1977	48	32	37	36	40		42	30	37	38	42	

(continued)

TYPING GUIDE SHEET

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications H$_2$0	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications H$_2$0	0	1/4 Max	1/2 Max	Max	LSD
			Sludge and water treatments											
			ppm											
Cr	0-15	1971	28	26	61	94	137	60**	30	31	56	101	136	43**
		1972	34	34	75	157	209	46**	47	34	79	166	275	41**
		1973	34	34	79	122	147	30**	39	35	75	101	151	12**
		1974	34	33	57	105	201	56**	38	36	78	121	179	40**
		1975	34	35	78	121	207	45**	38	31	74	115	184	25**
		1976	35	39	102	166	342	44**	40	40	75	111	213	29**
		1977	36	38	118	201	385	51**	38	41	74	93	233	65**
	15-30	1973	43	28	46	63	71	22*	46	26	56	68	73	28**
		1974	41	31	53	61	66	14**	45	30	50	70	70	23**
		1975	39	30	40	61	66	18**	47	32	43	55	71	15**
		1976	42	32	49	61	85	20**	46	33	51	64	90	29**
		1977	45	34	51	70	78	23**	50	32	49	56	91	17**
	30-46	1971	53	39	49	47	53		56	39	52	48	49	
		1972	62	41	49	61	75	19*	60	45	52	56	71	
		1973	57	36	46	46	57		71	38	49	45	54	
		1974	52	35	42	42	50		51	34	45	46	52	
		1975	47	40	45	45	50		56	35	44	43	52	12*
		1976	55	36	47	49	54		59	36	44	45	53	11*
		1977	57	36	48	47	53		61	34	49	45	58	16*
	61-76	1973	58	54	56	55	58		61	47	56	54	60	
		1974	59	51	56	55	56		57	50	56	54	55	
		1975	60	46	56	54	57		61	46	57	50	54	
		1976	61	49	58	55	60		63	46	56	52	58	
		1977	57	47	56	51	58		60	47	55	56	59	

(continued)

TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications H_2O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications H_2O	0	1/4 Max	1/2 Max	Max	LSD
			Sludge and water treatments											
			ppm											
Pb	0-15	1971	21	18	39	55	75	24**	20	20	29	56	73	21**
		1972	36	34	64	98	125	34**	34	35	55	102	145	34**
		1973	26	26	47	72	93	25**	29	26	48	58	98	12**
		1974	20	20	41	56	103	28**	20	20	49	64	90	22**
		1975	30	30	55	76	111	23**	27	29	50	66	103	15**
		1976	32	38	67	93	170	23**	37	32	47	68	120	7**
		1977	28	31	64	97	183	31**	27	32	51	62	120	27**
	15-30	1973	26	25	33	37	46	14**	27	28	35	41	43	10*
		1974	30	28	36	44	43	9**	28	32	39	47	48	11**
		1975	25	11	13	24	26		18	13	19	20	22	
		1976	27	31	40	41	53	15**	30	31	43	44	55	17**
		1977	23	26	34	40	80	11*	27	24	30	34	49	10**
	30-46	1971	36	27	30	27	32		28	29	32	27	32	
		1972	34	29	22	29	38		29	33	29	28	36	
		1973	28	22	25	30	26		29	24	28	25	28	
		1974	31	24	32	28	29		30	31	31	31	31	
		1975	26	26	30	27	27		29	24	26	26	26	
		1976	35	31	32	30	34		28	31	36	30	32	
		1977	26	23	26	25	28		29	23	30	25	26	
	61-76	1973	23	22	21	22	25		23	21	24	27	24	
		1974	32	29	28	33	33		27	30	33	29	30	
		1975	20	24	21	27	16		25	25	24	27	25	
		1976	30	30	29	31	29		29	26	27	28	29	
		1977	35	34	30	34	31		32	28	29	28	34	

(continued)

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TABLE 19. (continued)

Parameter	Depth cm	Year	Continued sludge applications						Terminated sludge applications					
			Sludge and water treatments											
			H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
			Units											
pH	0-15													
		1972	5.7	5.4	5.3	5.3	5.1		6.0	5.4	5.3	5.2	5.2	
		1973	6.4	6.1	6.1	6.0	5.7		6.6	6.0	6.1	6.0	5.8	0.5**
		1974	6.4	6.2	6.1	5.9	6.0		6.6	6.1	6.4	6.2	6.1	
		1975	6.6	6.5	6.3	6.1	6.0		6.9	6.6	6.5	6.4	6.3	0.4**
		1976	6.9	7.0	6.5	6.2	5.9	0.8**	7.1	6.8	6.9	6.9	6.7	
		1977	6.2	6.2	5.8	5.4	5.3	0.5**	6.4	6.2	6.2	6.1	5.9	
	15-30	1973	5.4	5.8	5.4	5.4	5.0	0.5*	5.7	5.6	5.5	5.3	5.2	0.3*
		1974	5.2	5.5	5.4	5.2	4.8	0.4*	5.3	5.6	5.4	5.3	5.1	
		1975	5.5	5.7	5.5	5.3	5.0	0.4*	5.6	5.9	5.5	5.5	5.4	
		1976	5.2	5.6	5.2	5.0	4.8		5.5	5.7	5.5	5.3	5.0	
		1977	5.1	5.3	5.0	4.9	4.6		5.6	5.6	5.2	5.1	5.1	
	30-46	1972	5.1	4.9	4.7	4.5	4.4		5.7	4.9	5.1	4.8	4.8	0.6*
		1973	5.1	5.2	5.0	5.0	4.7	0.2*	5.8	5.2	5.4	4.9	5.3	
		1974	5.3	5.1	5.0	4.9	4.5		5.9	5.1	5.3	4.8	5.1	0.5*
		1975	5.2	5.2	5.0	4.8	4.7		6.1	5.2	5.2	4.9	5.0	0.8*
		1976	5.0	4.7	4.7	4.4	4.4		6.1	4.8	4.9	4.6	4.9	
		1977	4.7	4.6	4.3	4.3	4.0		5.7	4.3	4.6	3.8	4.6	1.1*
	61-76	1973	6.4	5.0	5.9	5.4	5.8		6.8	5.2	6.1	5.5	6.3	
		1974	6.7	5.2	5.7	5.3	5.7		7.0	5.1	6.0	5.7	6.5	
		1975	6.7	5.2	5.8	5.7	5.7		7.5	5.3	6.2	5.8	6.1	
		1976	6.5	4.4	5.4	5.2	5.2		6.9	4.8	5.6	5.3	4.9	
		1977	6.8	5.0	5.6	5.3	5.5		7.3	5.1	5.9	5.6	6.5	

a/ Concentrations are on a dry-weight basis.

b/ After 1973, P applications were terminated and sludge applications were continued after 1972 only on split-plots formerly treated with superphosphate.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

large quantities were added as constituents of sludge. Soil Ca contents were not affected by sludge applications below the plow layer. Concentrations of Mg in the soil surface were not affected by sludge applications. But in the 15 to 30 and 30 to 46 cm soil depths irrigating with well water or maximum amounts of sludge appeared to have increased total Mg concentrations in plots where sludge applications were terminated after 1972. It seems likely that these results were due to natural soil variations since similar effects were not observed in plots where sludge applications were continued beyond 1972. Concentrations of Fe were frequently higher in the soil surface of plots irrigated with maximum rates of sludge or well water when compared to soil levels in unirrigated control plots. Iron concentrations in sludges were equivalent to natural levels in soils and thus these differences in soil levels were probably due to natural soil variations rather than to treatments. Like Fe, concentrations of Mn in sludges were too low in comparison to natural levels in soils to expect total concentrations of the element to be increased in soils as a result of accumulative sludge applications. As expected total Mn concentrations were not affected at any soil depth.

Zinc concentrations in sludges, on the average, were more than 80 times higher than natural soil levels. High levels in sludges were reflected by increased levels in sludge-amended soil to depths of 30 cm and frequently showed increased levels in the 30 to 46 cm soil depth of maximum-sludge-treated plots. Concentrations of Cd in sludges were usually 400 times higher than levels in uncontaminated soils. Thus, sludge applications caused marked increases in levels of Cd in 0 to 15 and 15 to 30 cm depths. Concentrations of Cd in soil increased with successive years of application, but there was little evidence that levels of the element were increased in soil depths below 30 cm. Concentrations of Cu in sludges were generally more than 50 times higher than levels in unpolluted soils. Thus, Cu concentrations in soil were significantly increased to depths of 30 cm by annual sludge applications. In some years Cu levels were significantly higher in the 30 to 46 cm soil depth of plots irrigated with well water or maximum amounts of sludge as compared to unirrigated control plots. But as was the case for some other elements this was probably due to natural variations in soil composition rather than treatment effects. Concentrations of Ni in sludges were about 25 times higher than those expected in normal soils. Therefore, the marked increases of Ni in the soil surface of sludge-amended plots were as expected. However, there was little evidence that Ni concentrations were increased by sludge applications in soil depths below 15 cm, even though plowing operations usually disturbed soil to depths slightly deeper than 15 cm. Concentrations of Cr in sludges generally exceeded levels in uncontaminated soils by about 60 times. These relatively high Cr concentrations were distributed, in sludge-amended soil, to a depth of 30 cm. Concentrations of Pb in sludge was about 40 times higher than levels in agricultural soils. These higher levels in sludge generally caused increased Pb concentrations in the 0 to 15 and 15 to 30 cm soil depths of sludge-amended plots.

Agricultural limestone was applied in 1972 and 1974 on all plots at rates calculated to increase the soil pH to about 6.5. But this pH level was never attained in soils treated with ½-maximum and maximum sludge applications. During the last two years of the study soil pH in the 0 to 15 cm depth was significantly less where maximum amounts of sludge were applied as compared to the pH of surface soil in control plots. At the 15 to 30 and 30 to 46 cm soil depths pH was low in comparison to values in the soil surface. Subsoil samples from maximum-sludge-treated plots frequently had lower pH levels than those from control plots. The pH level in soils materials deeper than 61 cm tended to be higher than those observed at depths between 15 to 46 cm.

Exhibited in Table 20 are 0.1 N HCl extractable concentrations of several elements in various depths of soil where soybeans were continuously grown for 8 years. Because results were not significantly different between plots with and without supplemental P fertilization through 1974, these data were combined according to sludge or water treatment. Extractable P concentrations are discussed later in connection with other sludge and soil data for P levels. For the two highest sludge loading rates, surface soil contained higher extractable levels of K than soil in control plots. At soil depths of 15 to 46 cm, extractable K levels were generally higher in maximum-sludge-treated plots and plots irrigated with well water as compared to levels in unirrigated soil. Also for Na, extractable levels were higher in the soil surface of maximum-sludge-treated and water irrigated plots than in non-irrigated plots. Extractable levels of Na in soil from water irrigated plots were higher than in plots treated with maximum rates of sludge, and this was generally true for all soil depths. Extractable Ca concentrations were significantly higher in the surface of soil treated with the two higher sludge loading rates than in the surface of control plots, regardless of whether or not the latter was irrigated with water. Extractable Ca concentrations in subsoil were not affected by treatments. The lowest concentrations of extractable Ca were in soil depths between 15 and 46 cm except for plots irrigated with well water. In the surface of soil treated with the higher sludge loading rates, extractable Mg contents tended to be increased over levels in control plots. At lower soil depths extractable Mg in sludge-treated plots were not significantly different from levels in plots irrigated with well water, but both had higher contents than soil in unirrigated plots. Extractable Fe concentrations were increased in the 0 to 30 cm soil depth by sludge applications. In the 0 to 15 cm soil depth extractable Mn concentrations were also increased by sludge applications. In soil at depths between 15 to 46 cm, extractable Mn concentrations tended to be somewhat less in plots treated with sludge or irrigated with well water as compared to levels in unirrigated plots. Extractable concentrations of Zn and Cd were markedly increased in soil depths of 0 to 30 cm by sludge applications. In the 30 to 46 cm soil depth extractable Zn and Cd concentration were increased only by maximum sludge applications and no differences in concentrations were observed at soil depths of 61 to 76 cm. Extractable Cu concentrations in soil surface were increased by sludge applications. But in the 15 to 30 cm depth only the two highest sludge loading rates caused a higher extractable Cu concentration. At deeper soil depths, there was little evidence that extractable Cu concentrations were affected by treatments. Extractable Ni concentrations were higher in the surface of soil treated with the two highest sludge loading rates, but levels were not affected in soil depths greater than 15 cm by sludge applications. Concentrations of extractable Cr and Pb were markedly increased to depths of 30 cm by sludge applications and to a lesser extent in the 30 to 46 cm soil depth.

TABLE 20. CONCENTRATIONS OF 0.1 N HCl EXTRACTABLE ELEMENTS IN BLOUNT SILT LOAM SOIL.[a/][b/]

Element	Soil depth (cm)	Year	Sludge application rates H_2O	 0	 1/4 Max	 1/2 Max	 Max	 LSD
			ppm					
K	0-15	1971	226	253	260	318	351	42**
		1972	161	152	185	234	285	18**
		1973	176	190	194	232	243	34**
		1974	216	219	234	236	277	21*
	15-30	1973	194	128	169	173	239	26**
		1974	225	143	176	184	228	28**
	30-46	1971	377	228	319	327	349	49*
		1972	192	91	126	142	169	34**
		1973	266	148	199	232	274	49*
		1974	329	138	218	254	312	86**
	61-76	1973	192	255	232	265	209	
		1974	270	318	327	331	306	
Na	0-15	1971	119	15	22	25	33	10**
		1972	106	18	31	46	61	10**
		1973	88	20	21	25	29	5**
		1974	53	16	19	24	34	3**
	15-30	1973	123	16	24	26	32	8**
		1974	98	19	23	27	34	5*
	30-46	1971	62	25	36	40	58	5**
		1972	106	17	31	46	61	10**
		1973	131	27	34	38	54	20**
		1974	119	22	28	36	50	13**
	61-76	1973	78	31	52	51	67	10**
		1974	79	35	57	58	73	11**
Ca	0-15	1971	1550	1588	1726	2089	2814	378**
		1973	1524	1640	2182	2147	2154	329**
		1974	2397	1930	2866	3278	3808	646**
	15-30	1973	1549	1360	1491	1354	1505	
		1974	1677	1424	1547	1628	1757	

(continued)

TABLE 20. (continued)

Element	Soil depth (cm)	Year	Sludge application rates H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm					
Ca	30-46	1971	2500	1148	1442	1401	1492	
		1973	2131	1392	1710	1604	1950	
		1974	3061	1519	1751	1790	2324	583**
	61-76	1973	12587	1742	8094	2642	10254	
		1974	19644	2349	12273	5472	17348	
Mg	0-15	1971	617	577	576	709	889	154**
		1973	506	482	715	630	646	86*
		1974	593	356	735	754	768	
	15-30	1973	570	378	473	403	487	79*
		1974	733	470	544	636	645	
	30-46	1971	1776	527	893	948	1345	528**
		1973	875	361	560	570	794	
		1974	1228	221	456	526	790	371**
	61-76	1973	4618	660	3779	1207	4368	
		1974	3403	713	2378	1589	3027	
Fe	0-15	1971	405	420	488	768	1006	
		1972	214	181	506	1116	1787	216**
		1973	502	465	781	1098	1495	131**
		1974	763	715	960	1221	1819	160**
	15-30	1973	616	536	773	692	865	94**
		1974	532	419	612	608	723	83**
	30-46	1971	1667	1664	1977	1672	1791	128**
		1972	573	317	428	480	659	115**
		1973	770	761	830	694	855	
		1974	1004	899	1060	879	968	
	61-76	1973	455	735	505	820	516	
		1974	531	942	622	849	594	

(continued)

TABLE 20. (continued)

Element	Soil depth (cm)	Year	Sludge application rates					
			H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm					
Mn	0-15	1971	149	176	206	262	298	
		1972	117	136	288	489	548	82**
		1973	314	431	480	560	532	113**
		1974	568	753	820	880	811	112*
	15-30	1973	188	398	377	342	340	
		1974	156	358	346	328	276	88*
	30-46	1971	140	219	164	121	140	44**
		1972	79	89	84	82	114	
		1973	150	364	254	202	166	85*
		1974	239	525	419	291	251	
	61-76	1973	158	126	137	133	140	
		1974	187	192	180	172	172	
Zn	0-15	1971	13	13	41	148	298	65**
		1972	8	13	70	193	316	28**
		1973	16	13	74	144	243	25**
		1974	8	12	66	136	252	30**
	15-30	1973	7	10	25	44	70	15**
		1974	4	7	26	56	64	13**
	30-46	1971	11	10	12	12	14	2*
		1972	8	9	10	17	31	6**
		1973	7	10	9	9	12	2*
		1974	21	23	27	31	34	
	61-76	1973	6	7	5	9	6	
		1974	5	7	7	9	11	
Cd	0-15	1971	0.18	0.26	3.16	8.33	13.55	2.29**
		1972	0.38	0.41	3.85	9.60	15.46	1.43**
		1973	0.30	0.38	4.08	8.73	13.88	1.38**
		1974	0.24	0.40	4.45	8.66	14.63	1.63**
	15-30	1973	0.74	0.27	1.33	1.46	4.03	0.96**
		1974	0.19	0.38	1.63	3.34	4.16	0.79**

(continued)

TABLE 20. (continued)

Element	Soil depth (cm)	Year	Sludge application rates H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm					
Cd	30-46	1971	0.37	0.21	0.20	0.39	0.29	
		1972	<0.10	0.11	0.23	0.64	0.99	0.30**
		1973	<0.10	<0.10	<0.10	0.12	0.23	0.07*
		1974	<0.10	<0.10	0.12	0.12	0.26	0.09**
	61-76	1973	<0.10	<0.10	<0.10	<0.10	<0.10	
		1974	0.23	0.11	0.24	0.22	0.31	
Cu	0-15	1971	4.8	4.9	23.5	49.9	74.0	11.2**
		1972	4.4	4.8	20.0	42.0	71.8	6.3**
		1973	5.2	15.6	23.5	39.1	60.4	14.0**
		1974	3.1	3.9	16.2	33.1	62.5	6.3**
	15-30	1973	3.7	8.9	8.9	14.0	20.2	5.7**
		1974	2.4	2.4	7.8	14.7	18.0	3.0**
	30-46	1971	3.8	4.2	4.5	4.9	4.9	
		1972	6.1	6.4	6.3	7.8	10.1	1.8**
		1973	5.5	7.9	6.3	8.0	6.4	
		1974	3.9	3.9	4.1	4.5	4.3	
	61-76	1973	2.7	5.1	3.4	5.8	3.2	
		1974	2.1	4.5	3.1	4.0	2.6	
Ni	0-15	1971	3.4	4.7	7.1	9.7	12.8	2.3**
		1972	3.6	3.6	6.4	11.6	16.3	1.5**
		1973	2.7	3.6	4.9	8.4	10.8	1.5**
		1974	2.9	4.3	5.8	7.3	9.7	1.1**
	15-30	1973	2.1	3.7	4.0	3.8	5.0	
		1974	2.5	4.2	4.8	4.9	5.0	
	30-46	1971	7.0	7.0	5.8	5.1	6.0	1.3*
		1972	4.2	4.3	3.6	3.8	4.2	
		1973	3.5	4.6	3.8	2.6	2.6	
		1974	3.3	3.6	3.5	2.2	2.9	
	61-76	1973	4.8	2.4	3.0	3.7	3.9	
		1974	5.1	2.5	3.7	4.1	6.7	

(continued)

TABLE 20. (continued)

Element	Soil depth (cm)	Year	Sludge application rates H_2O	0	1/4 Max	1/2 Max	Max	LSD
			ppm					
Cr	0-15	1971	0.64	0.58	9.22	26.8	44.6	10.9**
		1972	0.48	0.50	7.99	24.2	46.8	5.51**
		1973	1.02	2.79	8.12	26.5	43.5	7.31**
		1974	1.11	0.78	8.04	22.4	55.0	
	15-30	1973	<0.20	<0.20	2.78	4.84	7.26	
		1974	0.14	0.29	2.15	6.55	6.73	2.10**
	30-46	1971	1.87	1.30	1.80	1.82	2.14	0.30*
		1972	0.42	<0.20	0.28	1.05	1.81	0.78**
		1973	0.98	--	0.82	0.93	1.36	0.44*
	61-76	1973	1.07	0.50	0.52	0.59	0.84	
Pb	0-15	1971	4.17	5.29	16.4	36.0	51.9	9.37**
		1972	2.90	2.41	14.1	36.3	62.8	6.89**
		1973	5.56	5.34	17.4	30.8	52.0	4.77**
		1974	5.40	5.08	14.0	27.1	47.7	5.01**
	15-30	1973	4.82	5.57	8.82	11.2	15.3	2.02**
		1974	5.68	4.32	7.99	12.9	15.8	1.93**
	30-46	1971	6.41	4.64	5.86	5.12	6.50	
		1972	3.62	2.19	2.64	3.97	6.63	1.59*
		1973	5.63	4.22	3.61	4.78	5.50	
		1974	4.43	2.88	3.20	4.12	4.42	
	61-76	1973	5.31	5.60	4.64	5.31	5.22	
		1974	4.59	4.94	5.18	4.79	3.87	

a/ Concentrations are based on dry weight of soil.
b/ Plots with and without sludge were planted to soybeans each year.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Except for Na there was no indication that 0.1 *N* HCl extractable concentrations of the several elements in soil at a depth of 61 to 76 cm had been affected by sludge applications. Well water and sludge used to irrigate soybean plots contained, as an average, 160 to 240 and 98 to 123 ppm, respectively, of Na. Apparently the Na did not accumulate to high concentrations in the soil profile, within depths that were examined (Table 19) but extractable levels were probably temporarily increased at the time samples were collected each spring.

Yield Responses of Soybeans to Phosphorus, Sludge, and Water Applications--

The data presented in Table 21 shows that soybeans responded to sludge application every year, but not always in the same way for those growing on maximum-sludge-treated plots. During the first year of the study, sludge and water applications significantly increased bean yields over those harvested from nonirrigated plots. In the second year, yields from sludge and water-irrigated plots were higher than those from nonirrigated plots. But in this year, maximum-sludge-treated plots produced higher bean yields than plots irrigated with well water. During the third year sludge-treated plots produced higher soybean yields than control plots, but during this year there were differences in yields from control plots with and without water. In 1972, following a year in which sludge applications supplied a season total of about 135 mt/ha of solids on maximum-sludge-treated plots, yields were severely reduced on maximum-sludge-treated plots as compared to all other plots. The reduction in yields were significantly greater on maximum-sludge-treated plots that also received superphosphate applications. About 90% of the plants on maximum-sludge-treated plots died in the seedling state after showing severe P toxicity symptoms.

After sludge applications were terminated in 1972 and not resumed until after the 1973 growing season on plots which had, in previous years, received superphosphate applications, yields in 1973 were not related to treatment except that those from ½-maximum and maximum-sludge-treated plots formerly treated with phosphate fertilizer had higher yields than control plots. In 1975, plots treated in 1974 and 1975 with ½-maximum and maximum sludge applications, as well as plots formerly treated with these rates, produced higher yield than plots irrigated with water but were not higher than yields from nonirrigated control plots. However, in the seedling stage, soybeans growing on plots treated with maximum amounts of sludge showed phosphorus toxicity symptoms in 1975, which were not as severe as in 1972 and most of the plants recovered within about 3 weeks. Where sludge applications were continued, soybean yields were significantly less in 1976 on plots treated with maximum amounts of sludge as compared to plots treated with lesser amounts of sludge. During the last year, considerably more plants growing on maximum-sludge-treated plots succumbed to P toxicity as compared to losses on the same plots during the previous 1975 growing season.

TABLE 21. YIELD RESPONSES OF SOYBEAN (BEESON CULTIVAR) TO PHOSPHORUS, SLUDGE, AND WATER APPLICATIONS.

Year	P Treatment	Rate of sludge application (mm) 0	6.4	12.7	25.4	Water[a]	LSD
	kg/ha	Yield mt/ha					
1969	0	2.28	3.02	3.24	3.36	2.92	0.36**
	118	2.54	2.99	3.14	3.50	3.49	
1970	0	2.01	2.77	3.02	2.85	2.57	0.32**
	118	1.98	2.68	2.58	3.20	2.59	
1971	0	1.80	1.93	2.10	2.13	1.50	0.24**
	118	1.53	1.87	2.08	2.12	1.74	
1972	0	2.04	2.55	2.74	0.93	1.64	0.75**
	118	2.26	2.98	2.84	0.21	1.98	0.43**
1973	[b] 0	1.68	1.90	2.00	2.11	1.10	0.70**
	[c] 0	1.48	1.64	2.08	1.97	1.22	0.38**
1974	[b] 0	1.48	1.74	1.79	1.79	1.34	0.32*
	[c] 0	1.44	1.71	2.00	2.12	1.74	0.39*
1975	[b] 0	2.73	2.37	2.94	2.75	1.86	0.59*
	[c] 0	2.42	2.83	3.34	3.04	2.09	0.76**
1976	[b] 0	1.72	1.62	2.01	1.64	1.20	0.41*
	[c] 0	1.63	2.13	2.37	1.14	1.57	0.61*

[a] Water application rates were the same as the maximum sludge rate and were applied on the same day.

[b] No sludge or water was applied after one application in 1972.

[c] Sludge or water was applied as in previous years, but not P.

*, ** Significantly different at P_0.05 and P_0.01, respectively.

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Changes in the Composition of Soybean Tissues--

The data presented in Table 22 shows that the uptake of several elements by soybeans were affected by sludge applications. Maximum sludge applications frequently resulted in higher concentrations of N in soybean leaf and petiole tissue, but not in bean and stalk residues. The latter tissues from maximum-sludge-treated plots often had lower N concentrations than similar plant parts from unirrigated control plots. But marked differences in magnitudes of N concentrations, that could be attributed to sludge applications, were never observed. Where sludge applications were never completely terminated, P concentrations in soybean tissues from maximum-sludge-treated plots frequently were higher than concentrations in tissues from control plots. Where sludge applications were terminated after one application in 1972, tissues from maximum-sludge-treated plots often contained less P than tissues from control plots and plots treated with lesser amounts of sludge. The magnitude of difference in K concentrations attributable to sludge applications was not great. In leaves and petioles from maximum-sludge-treated plots, K concentrations generally were not different from or tended to be lower than concentration in similar tissues from control plots. In 2 out of 7 years, K concentrations were significantly higher in beans from maximum-sludge-treated as compared to control plots. Where sludge applications were continued, maximum sludge rates significantly increased K concentrations in stalk residues and during the first and last 2 years where applications were terminated in 1972. Except for stalk residues, sludge application affected Na concentrations in soybean tissues very little. During a few years, beans from maximum-sludge-treated soil had higher Na concentrations. Where sludge was applied every year at maximum rates, Na concentrations were higher in stalk residues than in those collected from unirrigated control plots. Plots irrigated with well water produced stalk residues with higher Na contents than found in similar tissues from unirrigated control plots every year in which water was applied. Concentrations of Ca in leaf and petiole and stalk residue samples from maximum-sludge-treated plots were sometimes higher than those found in samples from control plots. But the opposite was found in beans. When differences in Ca concentrations were found in beans they were lower in samples from plots treated with maximum amounts of sludge. Although not observed in every year, Mg concentrations in all soybean tissues tended to be increased by maximum sludge applications. In 1972, when soybeans suffered from P toxicity, tissues from maximum-sludge-treated plots had significantly higher Fe concentrations than were found in tissues from control and lesser sludge-treated plots. In years when soybeans were not so severely affected by P toxicity conditions, Fe contents in tissues either were not affected by treatments or were lower in tissues from maximum-sludge-treated plots as compared to concentrations in tissues from control plots. Concentration of Mn in all tissues from maximum-sludge-treated plots were markedly increased in 1972 when plants were stunted by excessive levels of soluble P in the soil. In the year just previous to the development of the severe P toxicity and again when less severe symptoms were observed during the last year of the study, Mn concentrations were significantly increased in leaves and beans produced on plots annually treated with maximum rates of sludge. Concentrations of Zn and Cd were significantly increased in all soybean tissues by annual sludge applications. Zinc and Cd concentrations varied from year to year mainly as a function of amounts of sludge applied each year, but there was no indication that accumulations of either Zn or Cd in soil had substantially affected levels in soybean tissues.

(continued on Page 338)

TABLE 22. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS AND ASH CONTENTS OF LEAF AND PETIOLE, BEAN, AND STALK SAMPLES FROM SOYBEANS (BEESON CULTIVAR) GROWN ON BLOUNT SILT LOAM SOIL, WITH AND WITHOUT SLUDGE.[a]

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Constituent	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
N	1971	3.57	3.52	3.94	3.99	4.55	0.63**	3.75	3.59	4.13	4.06	4.54	0.36**
	1972	3.84	4.66	2.69	4.76	4.94	1.24*	4.43	2.96	3.71	5.10	3.94	
	1973	4.12	3.90	4.23	4.09	4.21		3.74	4.11	4.43	4.28	4.20	0.33*
	1974	3.98	3.81	3.98	4.40	4.53	0.40*	3.81	3.66	3.78	3.84	3.83	
	1975	4.58	4.21	4.29	4.83	5.01	0.58**	4.26	4.44	4.38	4.46	4.39	
	1976	4.10	4.34	4.10	4.21	4.48		3.38	4.46	4.47	4.39	4.10	0.70**
		Bean											
		%											
	1971	5.92	6.23	6.41	6.97	6.87		6.27	5.76	6.88	7.10	6.90	0.61**
	1972	6.50	6.54	6.37	5.93	5.90	0.44**	6.65	6.83	6.23	5.92	5.93	0.57**
	1973	6.49	6.33	6.26	5.76	6.48		6.28	6.49	6.33	6.16	5.95	0.29*
	1974	6.28	6.03	6.28	6.35	6.52		6.05	5.94	5.76	6.00	5.96	
	1975	6.51	6.32	6.29	5.64	5.88		6.21	6.48	6.39	6.32	6.18	
	1976	5.91	6.46	6.22	6.01	6.11		6.25	6.23	6.18	6.33	6.20	
		Stalk residue											
		%											
	1972	1.11	1.08	0.88	0.87	1.03		1.10	1.14	0.97	0.93	1.04	
	1973	0.94	0.93	0.74	0.66	0.76	0.17*	0.89	0.71	0.76	0.66	0.73	
	1974	1.25	0.97	0.92	0.94	1.11		1.07	1.00	0.85	0.97	0.87	
	1975	1.29	1.07	0.82	0.94	1.02	0.27*	1.12	1.20	1.03	0.95	0.77	0.19**
	1976	0.83	0.99	0.85	0.70	0.96		0.95	1.00	1.18	1.06	0.74	0.20*

(continued)

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TABLE 22. (continued)

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Constituent	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
P	1970	0.29	0.29	0.33	0.35	0.38	0.05*	0.28	0.28	0.32	0.35	0.37	
	1971	0.25	0.22	0.24	0.24	0.27		0.21	0.22	0.25	0.24	0.27	0.05**
	1972	0.38	0.35	0.42	0.44	0.50	0.09**	0.37	0.34	0.40	0.45	0.47	0.08**
	1973	0.26	0.24	0.29	0.27	0.23	0.04*	0.21	0.22	0.28	0.26	0.24	0.04**
	1974	0.38	0.39	0.41	0.43	0.43		0.35	0.35	0.38	0.38	0.37	
	1975	0.29	0.25	0.26	0.32	0.39	0.05**	0.23	0.26	0.26	0.24	0.23	0.02*
	1976	0.32	0.33	0.30	0.33	0.44	0.04**	0.27	0.31	0.33	0.30	0.28	0.04*
		Bean											
		%											
	1970	0.41	0.55	0.65	0.65	0.72		0.61	0.60	0.59	0.63	0.66	
	1971	0.61	0.57	0.57	0.55	0.65		0.50	0.48	0.56	0.53	0.58	
	1972	0.64	0.67	0.71	0.74	0.83	0.08**	0.55	0.60	0.58	0.76	0.82	0.19*
	1973	0.51	0.50	0.57	0.51	0.49	0.05*	0.41	0.43	0.54	0.54	0.47	0.06**
	1974	0.47	0.58	0.58	0.59	0.62		0.49	0.46	0.53	0.57	0.50	0.06*
	1975	0.60	0.57	0.54	0.62	0.60		0.47	0.55	0.52	0.50	0.46	0.06**
	1976	0.62	0.68	0.66	0.68	0.87	0.12**	0.61	0.61	0.66	0.62	0.58	
		Stalk residue											
		%											
	1972	0.09	0.14	0.14	0.19	0.37	0.11**	0.06	0.09	0.15	0.20	0.23	0.11**
	1973	0.08	0.07	0.08	0.07	0.07		0.07	0.06	0.07	0.07	0.07	0.08**
	1974	0.08	0.06	0.05	0.06	0.10	0.02*	0.06	0.05	0.06	0.07	0.04	
	1975	0.11	0.09	0.07	0.11	0.22		0.04	0.08	0.06	0.06	0.04	0.03*
	1976	0.07	0.07	0.09	0.12	0.29	0.08**	0.05	0.08	0.07	0.06	0.05	

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications: H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
K	1971	1.99	1.71	1.64	1.63	1.55	0.21*	2.06	1.89	1.73	1.71	1.66	0.10**
	1972	2.23	1.93	2.10	2.15	2.23		2.40	2.21	2.03	2.25	2.30	
	1973	1.78	1.43	1.56	1.70	1.57		2.10	1.87	1.60	1.66	1.84	
	1974	2.36	2.11	2.28	2.41	2.42		2.29	2.21	2.13	2.30	2.38	
	1975	3.11	2.70	2.72	2.72	3.31	0.45*	3.00	2.81	2.86	2.87	2.75	
	1976	2.28	2.24	2.11	2.13	2.08		2.40	2.32	2.35	2.41	2.20	0.11*
		Bean											
		%											
	1970	1.76	1.74	1.80	1.80	1.82		1.41	1.72	1.80	1.86	1.88	
	1971	2.02	2.10	2.08	2.16	2.24	0.11*	2.02	2.01	2.10	2.08	2.15	
	1972	1.82	1.87	1.90	1.90	2.00		1.77	1.84	1.77	1.96	1.95	
	1973	2.50	2.44	2.70	3.00	2.49		2.41	3.77	2.85	2.64	3.16	
	1974	1.77	2.26	1.86	2.56	2.69		2.41	2.43	2.51	2.32	2.24	
	1975	2.47	2.56	2.55	2.51	2.44		2.15	2.04	2.52	2.51	2.48	
	1976	2.41	2.42	2.43	2.46	2.64	0.11**	2.35	2.37	2.40	2.39	2.35	
		Stalk residue											
		%											
	1972	1.28	1.10	1.51	1.71	2.12	0.59*	1.46	1.09	1.50	1.92	1.95	0.55*
	1973	1.07	0.92	1.08	1.74	1.61	0.51*	1.05	1.12	1.21	1.45	1.44	
	1974	1.40	1.17	1.52	1.51	1.72	0.29*	1.43	1.32	1.42	1.52	1.60	
	1975	1.97	2.05	1.96	2.54	3.21	0.80**	1.96	2.06	1.99	2.40	2.51	0.38*
	1976	1.85	1.56	1.80	1.92	2.25	0.43**	1.42	1.69	1.83	1.91	1.80	0.34**

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and Petiole											
		ppm											
Na	1971	372	350	355	335	369		351	345	312	364	330	
	1972	236	137	147	207	246		268	113	125	251	226	
	1973	308	358	313	313	230		335	337	338	317	260	
	1974	388	605	425	572	528		399	519	537	418	475	
	1975	103	82	127	129	103		88	104	120	90	79	
	1976	378	325	333	315	494		472	414	406	360	431	
		Bean											
		ppm											
	1970	21	14	17	16	21		21	12	19	23	27	
	1971	6	11	5	10	13	5*	21	4	4	9	9	
	1972	11	10	11	10	29	9**	12	6	6	9	19	9**
	1973	18	18	18	16	23		18	15	18	24	20	
	1974	21	32	26	25	28		40	31	35	24	32	
	1975	19	25	28	20	19		27	29	33	28	24	
	1976	9	6	8	9	20	9**	8	10	6	7	8	
		Stalk residue											
		ppm											
	1972	1221	103	335	421	991	486**	1943	100	243	273	725	1042**
	1973	376	124	175	176	287	160**	207	116	162	219	236	
	1974	811	247	329	490	619	356**	633	233	297	308	323	
	1975	340	143	225	371	694	227**	227	166	211	246	279	
	1976	411	96	230	478	1398	653**	120	121	121	183	182	

(continued)

TABLE 22. (continued)

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Constituent	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
Ca	1971	1.72	1.88	2.11	2.28	2.08	0.36*	1.39	1.73	2.15	2.12	2.22	0.43**
	1972	0.77	0.88	1.25	1.17	1.06	0.32*	0.78	0.81	1.10	1.21	1.15	0.28*
	1973	1.94	1.58	1.90	1.92	1.67		1.48	1.68	1.92	1.54	1.76	
	1974	1.00	1.35	1.33	1.34	1.28		0.87	1.24	1.29	1.22	1.26	0.25*
	1975	0.92	1.13	1.26	1.32	1.30	0.22*	0.94	1.14	1.12	1.13	1.09	
	1976	1.35	1.34	1.80	2.09	1.95		1.51	1.17	1.33	1.26	1.53	0.25*
		Bean											
		%											
	1970	0.24	0.22	0.19	0.19	0.17	0.05**	0.19	0.26	0.27	0.18	0.18	
	1971	0.21	0.23	0.17	0.15	0.14	0.03**	0.22	0.21	0.16	0.17	0.16	0.03**
	1972	0.18	0.19	0.13	0.17	0.20	0.02**	0.19	0.18	0.14	0.18	0.19	
	1973	0.11	0.16	0.12	0.11	0.09	0.04*	0.11	0.12	0.11	0.10	0.08	
	1974	0.15	0.20	0.18	0.15	0.18		0.21	0.22	0.19	0.19	0.21	
	1975	0.20	0.21	0.18	0.19	0.18		0.19	0.16	0.21	0.19	0.18	
	1976	0.18	0.18	0.13	0.14	0.13	0.03**	0.18	0.17	0.18	0.18	0.17	
		Stalk residue											
		%											
	1972	0.65	0.73	0.77	0.81	1.04	0.24**	0.67	0.56	0.76	0.78	1.11	0.34**
	1973	0.81	0.92	0.76	0.86	0.86		0.85	0.95	0.89	0.71	0.92	
	1974	0.82	0.53	0.64	0.54	0.78		0.76	0.73	0.65	0.55	0.64	
	1975	0.53	0.63	0.51	0.62	0.58		0.46	0.62	0.58	0.50	0.44	
	1976	0.93	0.80	0.81	0.76	1.11	0.22**	0.72	0.85	0.84	0.73	0.80	

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications Sludge and water treatments H_2O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
Mg	1971	0.38	0.51	0.58	0.57	0.53	0.08**	0.33	0.44	0.60	0.59	0.53	0.08**
	1972	0.21	0.22	0.37	0.34	0.27		0.25	0.20	0.32	0.33	0.37	0.09**
	1973	0.39	0.34	0.45	0.41	0.37		0.31	0.34	0.42	0.40	0.39	
	1974	0.38	0.49	0.56	0.48	0.44		0.34	0.45	0.51	0.50	0.55	
	1975	0.23	0.27	0.33	0.31	0.32	0.06**	0.26	0.25	0.26	0.27	0.33	
	1976	0.42	0.36	0.47	0.44	0.50		0.38	0.29	0.33	0.31	0.45	0.08**
		Bean											
		%											
	1970	0.27	0.26	0.28	0.28	0.29		0.21	0.27	0.28	0.28	0.28	
	1971	0.26	0.27	0.26	0.27	0.28		0.26	0.26	0.26	0.27	0.28	
	1972	0.22	0.23	0.27	0.25	0.26	0.02**	0.21	0.22	0.21	0.27	0.26	
	1973	0.17	0.16	0.20	0.19	0.22	0.04*	0.16	0.17	0.19	0.20	0.21	0.03*
	1974	0.14	0.22	0.22	0.22	0.23	0.05*	0.18	0.21	0.14	0.20	0.17	
	1975	0.22	0.24	0.25	0.28	0.26		0.19	0.18	0.25	0.25	0.23	
	1976	0.23	0.23	0.25	0.26	0.28	0.02**	0.22	0.23	0.23	0.23	0.23	
		Stalk residue											
		%											
	1972	0.37	0.32	0.38	0.37	0.45	0.07*	0.35	0.30	0.38	0.35	0.45	
	1973	0.33	0.39	0.32	0.28	0.30		0.35	0.31	0.37	0.31	0.33	
	1974	0.49	0.54	0.58	0.48	0.49		0.54	0.54	0.57	0.52	0.55	
	1975	0.46	0.47	0.44	0.41	0.50		0.43	0.45	0.48	0.43	0.43	
	1976	0.38	0.42	0.39	0.48	0.60	0.08**	0.42	0.44	0.45	0.44	0.42	

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Fe	1971	131	137	135	139	114		122	134	136	128	112	
	1972	108	116	114	104	268	27**	110	109	98	106	190	57**
	1973	122	130	136	121	116		137	141	133	130	121	
	1974	117	160	141	144	116		113	151	142	145	137	
	1975	94	100	85	80	91		88	107	88	92	89	13*
	1976	130	120	106	97	114		114	115	103	105	95	
		Bean											
		ppm											
	1970	73	62	56	52	52	12*	48	61	59	49	76	
	1971	92	91	83	74	66	8**	81	86	76	76	71	9*
	1972	51	50	48	45	91	30**	50	45	38	43	61	15**
	1973	75	78	70	77	60	9*	74	73	74	72	65	
	1974	38	48	41	40	34		50	58	45	42	45	11**
	1975	66	74	68	52	44		81	61	60	56	51	
	1976	48	48	35	37	37		35	56	43	36	35	
		Stalk residue											
		ppm											
	1972	107	133	158	150	821	195**	86	118	146	126	540	103**
	1973	297	227	245	198	224		318	196	258	178	205	
	1974	133	156	114	125	151		109	153	144	214	130	
	1975	112	89	73	94	72		108	85	94	73	94	
	1976	111	82	87	74	77	22*	85	78	82	84	82	

(continued)

TABLE 22. (continued)

Constit-uent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Mn	1971	65	93	210	254	400	163**	42	75	155	239	275	161**
	1972	74	90	196	162	403	132**	59	90	97	236	319	168**
	1973	56	62	61	57	80		43	69	54	56	60	
	1974	92	97	91	110	82		58	99	78	76	89	
	1975	74	82	76	105	171	54*	50	95	65	64	80	
	1976	76	99	103	135	283	91*	65	93	73	72	88	
		Bean											
		ppm											
	1970	29	29	27	34	42		21	30	29	33	41	
	1971	28	31	39	43	53	16*	30	28	30	40	43	
	1972	17	20	20	19	29	8**	17	20	17	23	28	
	1973	25	27	25	25	27		22	27	23	24	23	8**
	1974	17	21	20	21	20		19	22	19	19	19	
	1975	21	24	22	22	23		24	24	23	23	22	
	1976	29	32	28	29	40	7*	27	30	28	27	27	
		Stalk residue											
		ppm											
	1972	31	48	56	47	287	123**	24	42	35	62	178	88**
	1973	26	27	27	25	36		20	28	24	21	27	
	1974	40	38	36	54	62		28	46	29	40	31	
	1975	36	39	27	39	62		25	41	26	25	25	
	1976	31	37	34	31	96		19	41	26	24	24	14**

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Zn	1971	36	45	113	164	277	62**	38	53	102	159	209	63**
	1972	43	44	177	198	471	127**	48	55	115	246	417	131**
	1973	39	37	87	125	202	59**	38	47	75	115	175	77**
	1974	37	49	103	132	143	15**	37	56	85	106	130	26**
	1975	33	34	87	140	208	50**	35	42	60	80	94	34**
	1976	30	34	96	196	349	78**	31	37	52	68	81	36**
		Bean											
		ppm											
	1970	75	57	67	72	79		43	59	71	74	87	22**
	1971	58	59	76	84	85	10**	57	57	68	79	85	11**
	1972	53	50	72	79	96	24**	46	52	72	84	93	15**
	1973	52	56	71	83	91	12**	49	54	70	73	82	15**
	1974	56	49	63	65	78	17*	49	54	59	62	66	9*
	1975	49	52	71	81	86	21**	50	53	61	67	69	6**
	1976	56	62	82	94	101	12**	58	60	70	75	78	9**
		Stalk residue											
		ppm											
	1972	11	16	57	89	368	101**	13	19	46	107	302	52**
	1973	12	16	29	52	103	46**	13	14	26	33	83	18**
	1974	14	17	32	68	119	26**	15	19	22	43	49	24**
	1975	12	14	33	78	163	63**	10	15	21	34	35	14**
	1976	11	11	45	95	279	107**	8	13	25	37	36	16**

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Cd	1971	0.28	0.28	1.07	3.24	7.82	1.81**	0.20	0.32	0.72	3.08	6.29	2.30**
	1972	0.43	0.67	2.74	3.72	14.87	4.67**	0.33	0.42	1.54	5.21	12.87	3.89**
	1973	0.53	0.48	0.12	2.03	4.55	0.83**	0.45	0.45	0.99	2.03	3.69	1.11**
	1974	0.18	0.22	0.89	2.73	5.78	1.01**	0.26	0.25	0.64	1.22	2.46	0.69**
	1975	0.12	0.09	0.38	1.49	6.74	3.62**	0.08	0.11	0.30	0.43	0.87	0.37**
	1976	0.20	0.18	1.84	5.85	14.19	3.08**	0.09	0.12	0.43	1.30	1.93	1.25**
		Bean											
		ppm											
	1970	0.15	0.12	0.36	0.51	0.85	0.37*	0.09	0.14	0.41	0.69	1.32	0.71*
	1971	0.53	0.27	0.54	0.88	1.80	0.77**	0.17	0.39	0.40	1.05	1.43	0.83**
	1972	0.21	0.36	0.64	0.87	2.41	0.53**	0.19	0.34	0.46	1.12	3.70	2.36*
	1973	0.23	0.23	0.37	0.62	0.85	0.25**	0.16	0.26	0.38	0.61	0.77	0.33**
	1974	0.13	0.31	0.31	0.57	0.92	0.42**	0.11	0.13	0.23	0.35	0.35	0.15*
	1975	0.09	0.07	0.34	0.72	1.69	0.31**	0.05	0.12	0.18	0.34	0.46	0.29**
	1976	0.07	0.12	0.46	1.05	2.14	0.33**	0.05	0.07	0.24	0.54	0.68	0.44**
		Stalk and residue											
		ppm											
	1972	0.09	0.47	1.42	3.04	14.33	9.48**	0.34	0.58	1.14	3.94	13.64	3.59**
	1973	0.06	0.09	0.72	1.47	2.82	0.73**	0.25	0.07	0.60	1.34	1.66	0.93**
	1974	0.08	0.10	0.65	2.20	4.71	1.18**	0.11	0.07	0.35	0.78	1.22	0.34**
	1975	0.35	0.27	1.30	2.38	6.01	2.41**	0.14	0.21	0.38	1.10	1.12	0.58**
	1976	0.08	0.23	1.68	3.78	10.64	1.08**	0.15	0.20	0.85	1.58	1.54	1.02**

(continued)

TABLE 22. (continued)

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Constit-uent	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Cu	1971	6.3	5.4	7.1	6.8	5.2		7.5	6.3	6.1	6.5	6.2	
	1972	7.3	7.0	7.9	7.1	9.8		10.5	9.7	9.0	9.0	8.2	
	1973	7.4	6.3	7.7	7.6	6.0		8.9	8.4	8.7	8.7	8.0	
	1974	7.1	7.7	9.3	9.6	7.4	1.9**	8.4	9.2	8.4	9.9	8.6	
	1975	8.2	6.5	6.7	10.4	8.5		8.9	8.8	7.4	7.5	7.5	
	1976	7.2	7.2	5.8	4.9	7.3		7.3	6.5	6.3	6.1	7.5	
		Bean											
		ppm											
	1970	13.8	13.6	13.2	12.2	11.0	1.5*	12.4	14.5	16.7	12.9	13.5	
	1971	10.0	10.8	10.4	9.2	9.3		11.6	11.9	11.0	10.0	9.6	1.6**
	1972	11.8	11.6	12.7	12.6	14.7	1.9**	14.4	14.3	11.8	13.6	14.5	
	1973	12.7	13.1	13.4	12.5	10.6		14.8	15.3	13.9	14.0	11.0	2.4**
	1974	6.9	13.7	11.0	13.0	10.3	3.8*	14.0	13.8	16.9	13.0	12.7	
	1975	11.5	12.7	11.6	8.8	8.3	3.2*	15.9	12.8	11.2	10.5	10.3	
	1976	14.0	14.9	12.9	10.0	12.0	1.9**	17.4	16.3	14.1	13.0	13.3	3.2**
		Stalk residue											
		ppm											
	1972	6.2	6.1	8.1	5.9	12.2	3.5*	8.8	8.7	9.0	6.6	9.8	
	1973	4.2	4.0	4.2	4.2	4.5		4.9	4.5	4.6	4.1	4.8	
	1974	5.3	4.9	5.5	6.1	5.6		6.5	6.0	5.4	5.7	5.7	
	1975	7.0	12.3	6.9	5.4	8.5		9.4	8.0	6.5	5.7	5.5	
	1976	3.9	4.8	5.1	3.8	6.8	1.8**	5.7	5.9	4.8	5.1	3.7	

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Ni	1971	2.2	2.8	4.4	4.2	5.6	2.2*	2.3	3.3	4.5	6.1	6.3	
	1972	2.4	1.9	6.5	5.7	12.8	4.9**	3.6	2.2	3.7	6.9	9.1	3.8**
	1973	3.4	3.3	4.6	7.3	5.4		4.0	5.0	5.3	5.5	6.3	
	1974	2.0	2.1	2.4	3.7	5.3	1.3**	1.5	2.6	2.8	3.7	4.3	1.7*
	1975	1.2	1.0	2.0	3.4	7.2	1.6**	1.3	1.3	1.9	2.0	2.7	0.8*
	1976	0.5	0.7	1.3	2.6	6.6	2.8**	0.5	0.8	1.0	1.3	1.8	
		Bean											
		ppm											
	1970	7.8	10.2	10.5	10.3	9.8		4.4	10.1	8.3	10.7	11.3	4.4*
	1971	8.1	11.7	15.0	16.2	18.6	6.5*	6.8	11.7	11.8	15.1	16.9	
	1972	4.8	6.2	13.8	9.5	34.2	13.2**	3.6	6.7	6.0	11.0	31.7	5.1**
	1973	7.3	10.1	11.6	12.1	14.4		7.0	11.7	10.1	13.0	12.9	
	1974	4.6	8.6	7.9	9.5	10.8	3.4*	5.4	11.2	12.1	7.6	10.3	3.6*
	1975	3.0	4.5	6.2	9.1	12.5	2.8**	2.8	6.4	5.8	6.7	8.0	
	1976	4.5	6.6	7.4	12.6	22.3	4.7**	3.9	8.5	6.6	7.8	8.6	
		Stalk residues											
		ppm											
	1972	0.9	1.3	2.1	2.3	13.3	3.7**	1.1	1.0	1.7	3.0	10.0	2.9**
	1973	1.5	1.3	1.7	2.1	3.2	1.2**	1.5	1.6	1.9	2.3	2.9	0.9*
	1974	0.7	1.2	1.3	1.5	2.8	1.0*	0.8	0.9	1.4	1.5	1.8	
	1975	0.6	1.0	1.0	1.8	4.8	1.6**	0.7	0.7	1.1	1.3	1.0	
	1976	0.6	0.8	1.3	2.3	10.0	4.5**	0.5	0.7	0.8	0.9	1.8	0.7*

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		ppm											
Cr	1971	0.7	0.9	0.8	1.0	0.9		0.8	0.7	0.9	1.0	0.9	
	1972	0.3	0.4	0.6	0.5	4.1		0.4	0.5	0.5	0.5	1.1	0.45**
	1973	0.8	1.2	1.5	1.3	1.2	0.34*	0.8	1.1	1.3	1.1	1.2	
	1974	0.4	1.5	1.1	0.5	1.0		0.9	1.5	1.2	1.4		
	1975	1.5	1.0	1.7	1.8	1.3		1.4	1.3	1.3	1.5	1.4	
	1976	0.52	0.47	0.62	0.57	1.16	0.39**	0.49	0.41	0.35	0.46	0.52	
		Bean											
		ppm											
	1971	0.59	0.72	0.82	0.58	0.75		0.78	0.56	0.72	0.70	0.83	
	1972	1.31	1.48	1.81	1.31	2.83	0.9**	0.90	0.98	1.15	1.48	2.06	0.7*
	1973	0.49	0.70	0.77	0.50	0.56		0.60	0.60	0.50	0.60	0.50	
	1974	0.74	0.90	0.93	0.87	1.40		0.66	0.77	0.74	1.04	0.81	
	1975	0.53	0.62	1.43	0.72	0.57		1.09	1.01	0.66	0.97	0.62	
	1976	0.74	1.00	0.55	0.74	0.36		0.74	1.83	1.31	1.12	1.83	
		Stalk residue											
		ppm											
	1972	1.46	1.31	1.96	1.96	8.46	3.15**	1.15	1.46	1.47	2.12	5.83	0.83**
	1973	3.12	1.15	2.73	2.42	1.89		1.11	1.18	1.67	1.92	1.77	
	1974	1.17	1.61	1.23	2.17	4.04	1.55*	1.30	1.43	3.35	2.48	2.28	
	1975	0.7	0.6	0.8	0.9	0.5		0.6	0.2	0.4	0.4	0.3	
	1976	0.3	0.8	0.9	1.3	1.4		0.5	0.4	0.2	0.5	0.5	

(continued)

TABLE 22. (continued)

Constituent	Year	Continued sludge applications: H_2O	0	1/4 Max	1/2 Max	Max	LSD	Terminated sludge applications: H_2O	0	1/4 Max	1/2 Max	Max	LSD
							Leaf and petiole						
							ppm						
Pb	1971	4.5	5.2	4.1	4.8	4.1		3.3	4.0	4.0	3.9	3.8	
	1972	4.1	4.6	5.5	4.8	6.9		3.7	5.0	4.9	5.1	5.2	
	1973	5.2	6.3	6.3	5.8	5.9		6.3	8.6	7.1	6.7	6.4	
	1974	3.9	2.4	3.7	3.4	3.8		3.0	3.8	4.7	3.8	4.3	
	1975	1.4	1.1	1.8	1.3	1.8		1.8	1.3	1.4	1.3	1.1	
	1976	3.0	2.0	2.5	2.7	3.4		3.3	1.9	2.1	1.7	2.3	
							Bean						
							ppm						
	1970	3.2	1.8	2.6	2.5	3.9		2.2	2.8	3.0	2.5	3.6	
	1971	4.4	6.2	6.0	6.4	7.5		7.6	4.1	4.4	7.0	7.9	
	1972	1.9	2.2	1.9	2.1	2.6		2.0	2.0	1.3	2.3	2.2	
	1973	4.4	3.1	3.2	3.6	2.7		5.3	2.6	3.1	2.4	2.5	
	1974	1.7	1.8	1.7	1.6	1.6		1.5	1.2	1.4	1.2	1.6	
	1975	0.8	1.7	1.3	1.1	1.0		0.7	0.8	0.6	1.0	0.8	
	1976	1.0	1.3	0.9	1.8	1.6		1.0	0.8	0.8	1.4	1.2	
							Stalk residue						
							ppm						
	1972	2.6	4.1	3.6	4.0	5.4		2.6	3.5	3.1	3.6	4.9	1.3*
	1973	2.5	2.9	2.6	2.7	2.4		2.7	2.1	2.8	2.8	3.2	
	1974	2.1	1.8	2.1	1.6	2.7	1.5*	1.1	1.9	1.1	1.3	1.6	
	1975	2.4	3.1	2.5	2.3	2.0		1.3	2.1	1.6	2.9	2.0	
	1976	5.1	4.0	3.3	5.2	4.0		3.7	4.0	5.7	4.1	4.6	

Sludge and water treatments

(continued)

TABLE 22. (continued)

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Constituents	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		Leaf and petiole											
		%											
Ash	1972	7.80	8.32	9.73	9.50	11.57	1.98*	8.00	8.07	8.97	9.57	10.23	0.81**
	1973	8.72	8.23	8.71	9.13	9.42	0.74**	8.36	8.68	9.02	8.96	8.84	
		Bean											
		%											
	1970	5.12	5.12	5.12	5.22	5.52		5.03	5.10	5.28	5.35	5.82	
	1971	5.20	5.29	5.21	5.28	5.51	0.19*	5.42	5.11	5.04	5.15	5.39	
	1972	5.20	5.17	5.38	5.71	6.38	0.83**	4.99	5.16	5.50	5.46	6.01	0.63**
	1973	5.09	5.00	5.19	5.14	5.82	0.57**	4.70	4.97	5.25	5.09	5.59	0.49*
	1974	5.00	4.99	4.95	5.00	5.20		4.83	4.78	4.98	5.05	4.80	
		Stalk residue											
		%											
	1972	5.34	5.10	6.73	6.84	10.57	1.59**	6.02	4.95	6.07	6.98	9.81	1.51**
	1973	6.01	5.65	5.59	6.54	7.01	0.88*	6.16	5.97	6.38	5.90	6.77	

a/ Dry-weight concentrations are reported for all measurements.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

By the third year after sludge applications were terminated on split plots in 1972, Zn and Cd concentrations in soybean tissues from sludge-treated plots decreased rather dramatically. Even though levels in tissues from plots formerly treated with maximum sludge loading rates contained higher levels of Zn and Cd than those from control plots during the last two years of the study, the sharp decline in concentrations suggest that the availability of metals for uptake is reduced with time after termination of applications. Except in beans, sludge treatments seldom affected levels of Cu in soybean tissues. During two years, stalk residues from maximum-sludge-treated plots had higher Cu concentration as compared to levels in similar samples, from control plots. However, in most years where sludge applications were continued Cu concentrations in beans were decreased by maximum sludge applications. Concentrations of Ni in all plant tissues were increased by higher sludge application rates in most years. Like those of Zn and Cd, concentrations of Ni in soybean plant tissues decreased when sludge applications were terminated. But unlike Zn and Cd, concentrations of Ni were higher in beans than in leaves and stalk residues. Difficulty was experienced in analyzing plant tissues for Cr concentrations. Except when soybeans suffered from P toxicity, concentrations of Cr did not appear to be significantly affected by sludge applications. Concentration of Pb in plant tissues appeared to be affected hardly at all by sludge treatments. Considering the relatively high levels of Cr and Pb in sludges, these data suggest that these two elements were rather unavailable for uptake by plants soon after incorporating them into the soil.

Ash contents of soybean plant tissues produced on maximum-sludge-treated plots were frequently higher than in those collected from control plots. When soybean yields and plant populations were severely reduced in 1972, by P toxicity, ash contents of soybean tissues were unusually high. As was the case for corn plant tissues, much of the increase in ash contents of soybeans can be accounted for by increased uptake of Si.

Comparison of Yield Responses and Chemical Composition of Three Soybean Cultivars--

In the spring of 1976, the cultivars Amsoy 71 and Wells were planted along with the Beeson cultivar which had been used throughout the study on all plots. In eight-row plots, Beeson beans were planted in the center two rows with Wells in two adjacent rows and Amsoy in the other two rows adjacent to Beeson. Then the Beeson cultivar was planted in the remaining two rows between plots. These three cultivars were resistant to phytophthora root rot which was an important factor in their selection because soybeans had been continuously planted on the plots for 7 years.

Yields of beans and uptake of several elements by the three cultivars are presented in Table 23. Where sludge was applied each year, Wells cultivars produced significantly lower yields of beans on maximum-sludge-treated plots as compared with the check plots or those plots treated with lower sludge-loading rates. The Beeson cultivars produced yields only on those plots that were significantly lower than those from the one-fourth- and one-half-maximum-sludge-treated plots. Yields from the Wells cultivar were lower on the plots on which treatment with maximum amounts of sludge was terminated in 1972, than from unirrigated plots. In general, the Amsoy and Wells cultivars responded

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TABLE 23. YIELD RESPONSE AND CHEMICAL COMPOSITION OF 1976 TISSUES FROM 3 SOYBEAN CULTIVARS GROWN ON BLOUNT SILT LOAM PLOTS, WITH AND WITHOUT SEWAGE SLUDGE.a/

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		mt/ha											
Bean Yields	Beeson	1.57	1.63	2.13	2.37	1.14	0.61*	1.20	1.72	1.62	2.01	1.64	
	Amsoy	1.46	1.77	2.16	1.93	1.28		1.44	2.22	1.77	2.02	1.81	
	Wells	1.78	2.16	2.56	2.71	1.37	0.60*	1.48	2.15	2.01	2.00	1.77	0.27*
		Leaf and petiole											
		%											
N	Beeson	4.10	4.34	4.10	4.21	4.48		3.38	4.46	4.47	4.39	4.10	0.70**
	Amsoy	4.21	4.46	4.06	3.91	4.33		3.60	4.56	4.51	4.24	3.82	0.58*
	Wells	3.83	3.94	3.87	3.87	4.23		3.69	4.08	4.23	4.03	3.70	
		Bean											
		%											
	Beeson	5.91	6.46	6.22	6.01	6.11		6.25	6.23	6.18	6.33	6.20	
	Amsoy	5.79	6.22	5.84	5.88	5.67		6.25	6.43	6.31	6.14	5.93	0.30**
	Wells	5.81	6.18	6.03	6.08	5.93		5.98	6.04	6.08	6.13	5.54	
		Stalk residue											
		%											
	Beeson	0.83	0.99	0.85	0.70	0.96		0.95	1.00	1.18	1.06	0.74	0.20*
	Amsoy	0.72	0.62	0.63	0.57	0.81		0.89	0.82	0.89	0.84	0.66	
	Wells	1.02	0.92	0.81	0.72	0.85		1.22	1.02	1.16	1.04	0.61	
		Leaves collected 44 days after planting (petiole removed)											
		%											
P	Beeson	0.35	0.34			0.64	0.29**						
	Amsoy	0.35	0.41			0.72	0.21*						
	Wells	0.36	0.36			0.72							

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		Leaf and petiole											
		%											
P	Beeson	0.32	0.33	0.30	0.34	0.44	0.04**	0.27	0.31	0.33	0.30	0.28	0.04*
	Amsoy	0.35	0.38	0.31	0.31	0.49	0.12**	0.29	0.36	0.36	0.32	0.30	0.05*
	Wells	0.31	0.33	0.29	0.32	0.44	0.09**	0.27	0.33	0.41	0.30	0.27	
		Bean											
		%											
	Beeson	0.62	0.68	0.66	0.63	0.87	0.12**	0.61	0.61	0.66	0.62	0.58	
	Amsoy	0.60	0.64	0.55	0.68	0.81	0.16**	0.57	0.59	0.59	0.58	0.49	
	Wells	0.60	0.68	0.50	0.63	0.82	0.17**	0.58	0.62	0.63	0.65	0.51	
		Stalk residue											
		%											
	Beeson	0.07	0.07	0.09	0.12	0.29	0.08**	0.05	0.08	0.07	0.06	0.05	
	Amsoy	0.06	0.07	0.05	0.13	0.29	0.09**	0.05	0.07	0.06	0.05	0.05	
	Wells	0.09	0.09	0.08	0.10	0.33	0.09**	0.06	0.06	0.07	0.06	0.06	
		Leaf and petiole											
		%											
K	Beeson	2.28	2.24	2.11	2.13	2.08		2.40	2.32	2.35	2.41	2.20	1.12*
	Amsoy	2.06	2.17	1.81	1.90	1.90		2.17	2.17	2.13	2.17	1.98	
	Wells	2.05	1.96	1.77	1.87	1.99		2.00	2.05	2.01	2.11	1.90	
		Bean											
		%											
	Beeson	2.41	2.42	2.43	2.46	2.64	0.11**	2.35	2.37	2.40	2.39	2.35	
	Amsoy	2.36	2.35	2.32	2.43	2.54	0.13**	2.27	2.33	2.27	2.31	2.29	
	Wells	2.32	2.37	2.35	2.40	2.53	0.08**	2.23	2.28	2.29	2.28	2.22	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		Stalk residue											
		---% ---											
K	Beeson	1.85	1.56	1.80	1.92	2.25	0.43**	1.42	1.69	1.83	1.91	1.80	0.34**
	Amsoy	1.44	1.07	1.14	1.44	1.56	0.28*	1.29	1.36	1.46	1.32	1.35	
	Wells	1.73	1.43	1.63	1.70	1.95	0.24*	1.51	1.44	1.57	1.61	1.48	
		Leaf and petiole											
		---ppm---											
Na	Beeson	378	325	333	315	494		472	414	406	360	431	
	Amsoy	389	403	382	324	525		539	508	494	440	408	
	Wells	316	367	298	337	486	122*	432	373	434	380	415	79*
		Bean											
		---ppm---											
	Beeson	9	6	8	9	20	9**	8	10	6	7	8	
	Amsoy	11	11	9	11	15		10	13	11	11	10	
	Wells	9	7	7	9	13	3**	6	6	6	8	7	
		Stalk residue											
		---ppm---											
	Beeson	411	96	230	478	1398	653**	120	121	121	183	182	
	Amsoy	295	77	159	368	1000	210**	85	77	108	96	109	
	Wells	413	101	185	442	768	307**	114	127	107	183	208	
		Leaf and petiole											
		---%---											
Ca	Beeson	1.35	1.34	1.80	2.09	1.95		1.51	1.17	1.33	1.26	1.53	0.25*
	Amsoy	1.70	1.52	2.21	2.27	2.51	0.74**	1.71	1.40	1.81	1.57	1.71	
	Wells	1.00	1.13	1.43	1.52	1.55		1.36	0.94	1.16	1.19	1.01	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		Bean %											
Ca	Beeson	0.18	0.18	0.13	0.14	0.13	0.03**	0.18	0.17	0.18	0.18	0.17	
	Amsoy	0.15	0.18	0.13	0.14	0.13	0.03*	0.18	0.16	0.18	0.18	0.12	
	Wells	0.18	0.17	0.16	0.16	0.19		0.17	0.15	0.16	0.15	0.15	
		Stalk residue %											
	Beeson	0.93	0.80	0.81	0.76	1.11	0.22**	0.72	0.85	0.84	0.73	0.80	
	Amsoy	0.90	0.70	0.75	0.79	0.99	0.15*	0.91	0.79	0.72	0.70	0.73	
	Wells	0.91	0.74	0.79	0.78	0.97		1.03	0.80	0.96	0.81	0.76	
		Leaf and petiole %											
Mg	Beeson	0.42	0.36	0.47	0.44	0.50		0.38	0.29	0.33	0.31	0.45	0.08**
	Amsoy	0.40	0.33	0.59	0.58	0.60	0.20**	0.41	0.31	0.41	0.40	0.51	0.11**
	Wells	0.37	0.34	0.49	0.47	0.50		0.37	0.25	0.33	0.34	0.39	0.08*
		Bean %											
	Beeson	0.23	0.23	0.25	0.26	0.28	0.02**	0.22	0.23	0.23	0.23	0.23	
	Amsoy	0.17	0.23	0.24	0.26	0.25	0.05*	0.22	0.21	0.23	0.23	0.18	
	Wells	0.24	0.24	0.25	0.26	0.28	0.02**	0.23	0.24	0.23	0.24	0.24	
		Stalk residue %											
	Beeson	0.38	0.42	0.39	0.48	0.60	0.08**	0.42	0.44	0.45	0.44	0.42	
	Amsoy	0.47	0.41	0.42	0.47	0.65	0.13**	0.53	0.45	0.46	0.43	0.45	
	Wells	0.47	0.39	0.40	0.41	0.52	0.07*	0.48	0.44	0.47	0.42	0.42	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
Leaf and petiole ppm													
Fe	Beeson	130	120	106	97	114		114	115	103	105	95	
	Amsoy	132	129	105	106	98	19**	123	124	109	101	92	23*
	Wells	105	109	98	88	99		97	103	99	94	79	12**
Bean ppm													
	Beeson	48	48	35	37	37		35	56	43	36	35	
	Amsoy	47	46	50	42	30		45	51	45	42	46	
	Wells	54	45	68	51	38		40	53	43	34	45	
Stalk and residue ppm													
	Beeson	111	82	87	74	77	22*	85	78	82	84	82	
	Amsoy	79	53	81	70	79		85	60	60	42	68	25*
	Wells	83	66	84	57	77		122	60	73	59	61	40**
Leaf and petiole ppm													
Mn	Beeson	76	99	103	135	283	91*	65	93	73	72	88	
	Amsoy	118	129	128	170	322	67**	98	122	107	91	114	
	Wells	76	103	104	143	346	99**	76	90	90	84	88	
Bean ppm													
	Beeson	29	32	28	29	40	7*	27	30	28	27	27	
	Amsoy	30	34	24	28	41	10*	28	32	28	27	27	
	Wells	27	30	28	28	39		25	30	28	27	26	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application H_2O	Ck	¼-Max	½-Max	Max	LSD	Terminated sludge application H_2O	Ck	¼-Max	½-Max	Max	LSD
							Stalk residue						
							ppm						
Mn	Beeson	31	37	34	31	96		19	41	26	24	24	14**
	Amsoy	32	30	27	45	105	50**	25	39	27	25	24	9*
	Wells	38	32	28	40	113	50*	30	35	33	22	27	
							Leaf and petiole						
							ppm						
Zn	Beeson	30	34	96	196	349	200**	31	37	52	68	81	36**
	Amsoy	39	39	118	223	381	81**	37	42	60	75	113	18**
	Wells	29	35	95	195	366	86**	31	34	46	71	91	20**
	LSD	8*	n.s.	n.s.	n.s.	n.s.		4*	5*	n.s.	n.s.	n.s.	
							Bean						
							ppm						
	Beeson	56	62	82	94	101	12**	58	60	70	75	78	9**
	Amsoy	53	60	76	93	96	11**	55	57	64	73	76	9**
	Wells	55	61	79	79	99	18**	57	60	66	77	80	10**
	LSD	n.s.	n.s.	n.s.	n.s.	2**		n.s.	n.s.	n.s.	3**	n.s.	
							Stalk residue						
							ppm						
	Beeson	11	11	45	95	279	107**	8	13	25	37	36	16**
	Amsoy	12	11	38	126	353	82**	10	16	19	30	45	17**
	Wells	13	11	43	88	277	73**	12	12	24	29	42	18*
	LSD	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	2*	n.s.	n.s.	n.s.	
							Leaf and petiole						
							ppm						
Cd	Beeson	0.20	0.17	1.84	5.85	14.19	3.08**	0.09	0.12	0.43	1.30	1.93	1.25**
	Amsoy	0.44	0.42	5.26	13.28	26.83	7.37**	0.23	0.31	1.57	3.33	5.84	2.98**
	Wells	0.09	0.15	1.65	5.73	16.56	5.13**	<0.06	<0.06	0.45	1.64	2.03	0.66**
	LSD	0.18*	0.18*	1.88*	5.46*	8.53*		0.14*	0.20**	0.70**	1.41**	2.70*	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		Bean											
		ppm											
Cd	Beeson	0.07	0.12	0.46	1.05	2.14	0.33**	0.07	0.07	0.24	0.54	0.68	0.44**
	Amsoy	0.16	0.20	0.46	1.33	2.42	0.76**	0.15	0.18	0.66	1.22	1.77	1.20**
	Wells	0.11	0.08	1.19	2.00	4.14	0.67**	<0.06	<0.06	0.23	0.59	0.79	0.48**
	LSD	n.s.	n.s.	0.43**	0.60*	1.00**		n.s.	n.s.	0.24*	0.36*	n.s.	
		Stalk residue											
		ppm											
	Beeson	0.08	0.23	1.68	3.78	10.64	1.18**	0.15	0.20	0.85	1.58	1.54	1.02**
	Amsoy	0.17	0.28	1.34	4.75	11.87	2.18**	0.15	0.22	0.54	1.65	2.02	1.43**
	Wells	0.46	0.60	4.10	7.93	18.86	2.64**	0.35	0.53	1.51	3.26	4.42	2.50**
	LSD	0.29**	0.25*	1.61**	2.35*	4.04**		0.14*	0.23**	n.s.	1.07**	1.89*	
		Leaf and petiole											
		ppm											
Cu	Beeson	7.2	7.2	5.8	4.9	7.3		7.3	6.5	6.3	6.1	7.5	
	Amsoy	7.4	7.0	6.4	4.5	6.3	1.8**	6.9	7.3	6.7	5.4	5.6	1.3*
	Wells	7.1	7.4	7.1	5.1	8.1	1.8*	8.1	7.8	6.4	5.9	5.9	
		Bean											
		ppm											
	Beeson	14.0	14.9	12.9	10.0	12.0	1.9**	17.4	16.3	14.1	13.0	13.3	3.2**
	Amsoy	14.3	14.7	13.2	10.4	11.5	1.7**	16.6	15.3	13.7	13.2	13.1	2.7**
	Wells	13.2	13.9	13.3	11.2	11.3	2.1**	16.0	15.0	13.4	12.4	12.7	2.1**
		Stalk residue											
		ppm											
	Beeson	3.9	4.8	5.1	3.8	6.8	1.8**	5.7	5.9	4.8	5.1	3.7	
	Amsoy	4.1	3.9	4.5	3.6	6.5	1.0**	4.3	4.9	4.0	4.8	4.1	
	Wells	5.5	5.5	5.3	4.6	5.9		5.8	6.4	5.1	4.8	5.3	

(continued)

TABLE 23. (continued)

Element	Cultivar	Continued sludge application						Terminated sludge application					
		H_2O	Ck	¼-Max	½-Max	Max	LSD	H_2O	Ck	¼-Max	½-Max	Max	LSD
		Leaf and petiole											
		ppm											
Ni	Beeson	<0.6	0.7	1.3	2.6	6.6	2.8**	<0.6	0.8	1.0	1.3	1.8	
	Amsoy	<0.6	0.7	0.9	1.5	5.2	1.2**	<0.6	0.6	1.3	1.0	6.9	
	Wells	1.1	0.9	1.9	2.9	11.9	2.2**	0.8	1.5	1.4	1.3	3.0	1.2*
		Bean											
		ppm											
	Beeson	4.5	6.6	7.4	12.6	22.3	4.7**	3.9	8.5	6.6	7.8	8.6	
	Amsoy	5.3	6.4	7.3	12.4	22.3	7.7**	4.2	8.2	6.5	6.7	6.9	
	Wells	6.3	6.5	7.1	10.6	20.3	4.2**	3.8	8.2	5.7	7.6	7.8	
		Stalk residue											
		ppm											
	Beeson	0.6	0.8	1.3	2.3	10.0	4.5**	<0.6	0.7	0.8	0.9	1.8	0.7*
	Amsoy	<0.6	<0.6	0.7	2.4	12.4	3.0**	0.8	0.7	<0.6	<0.6	0.8	
	Wells	1.1	1.1	1.5	2.8	10.2	3.1**	1.0	1.0	0.8	1.3	1.5	

a/ Dry weight basis.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

to sludge applications in about the same way as the Beeson cultivar, with respect to both yields and changes in chemical composition. Where sludge applications were continued all three cultivars, growing on maximum-treated plots, showed symptoms of P toxicity. Phosphorus toxicity symptoms eventually disappeared and by flowering stage they appear to be normal, but evidently the early stress was the cause of reduced yields.

Leaf samples from control and continuous maximum-sludge-treated plots that were collected 44 days after planting were analyzed for P. Those from maximum-treated plots had average P contents that were, or were almost, double those in leaves from control plots. Amsoy beans contained slightly lower concentrations of Zn than beans from Beeson and Wells when grown on continuous maximum-sludge-treated plots. Leaf and petiole samples of Amsoy contained higher concentrations of Cd than similar tissues from the Beeson and Wells cultivars. But beans from Wells cultivar contained significantly higher concentrations of Cd than beans from the other two cultivars. Thus, the leaf-Cd contents would not have been very useful in predicting high grain-Cd contents. All three cultivars had higher concentrations of Cu and Ni in beans than in their repsective leaf and petiole tissues.

WINTER WHEAT ON PLOTS PREVIOUSLY PLANTED TO SOYBEANS

General Description

After soybeans were harvested in 1976 the plots were disced, roto-tilled, rolled and seed of the winter wheat variety Abe was sown with a small grain drill in all plots on October 4th. Whole plant samples were collected in May 1977 when heads had just begun to emerge from the boot. A strip 81 cm wide was harvested from the center of each plot on June 24 and the grain was separated by the use of a small stationary thresher. After weighing the grain and stover from each plot, 500 g subsamples of each were collected for analyses.

Discussion of Results

Wheat Grain Yields and Concentrations of Selected Elements in Whole Plants, Grain and Stover--

Grain and stover yields of wheat are shown in Table 24. Where sludge applications were terminated in 1972 yields were significantly less on plots which, when planted to soybeans in previous years, had been irrigated with well water. Symptoms of P toxicity or any other toxic condition were not observed in wheat, but plants growing on continuous maximum-sludge-treated plots appeared to mature too early causing a reduction in grain-filling.

Maximum sludge applications, and sometimes lesser sludge loading rates, caused significant changes in the chemical composition of wheat tissues which can be seen from the data reported in Table 25. Although concentrations of N, P, K, Na, Ca, and Mg were often increased, as a result of previous maximum applications of sludge, in one or more wheat plant tissues, none were in excess of the range expected in normal plants. Concentrations of Fe were increased only in grain by long-term annual maximum sludge applications, but

TABLE 24. GRAIN AND STOVER YIELDS OF WHEAT GROWN IN 1977 ON PLOTS PREVIOUSLY PLANTED TO SOYBEANS FROM 1969 THROUGH 1976.

Continued sludge applications						Terminated sludge applications					
Sludge and water treatments											
H_2O	0	1/4	1/2	Max	LSD	H_2O	0	1/4	1/2	Max	LSD
Grain											
mt/ha (13.5% moisture)											
3.01	3.90	3.33	3.13	2.11	n.s.	2.78	4.34	4.39	3.96	3.24	1.16*
Stover											
mt/ha (dry wt.)											
2.86	4.11	4.60	4.68	3.98	n.s.	2.61	4.50	4.83	4.46	4.27	n.s.

* Significantly different at $P \leq 0.05$.
n.s. Not Significantly Different

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TABLE 25. CONCENTRATIONS OF SELECTED ELEMENTS IN WHOLE PLANTS, GRAIN, AND STOVER SAMPLES OF WHEAT COLLECTED IN 1977 FROM PLOTS PREVIOUSLY PLANTED TO SOYBEANS FOR 8 SUCCESSIVE YEARS.[a/]

Chemical element	Type of sample	Continued sludge applications						Terminated sludge applications					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		%											
N	Plant	2.15	2.11	2.64	2.88	2.93	0.49**	1.96	2.38	2.13	2.18	2.57	0.30*
	Grain	2.35	2.11	2.83	3.07	3.84	0.90**	2.21	2.32	2.37	2.27	2.28	n.s.
	Stover	0.42	0.32	0.74	0.89	1.29	0.36**	0.27	0.33	0.37	0.42	0.55	0.16**
P	Plant	0.17	0.30	0.42	0.49	0.51	0.17**	0.23	0.26	0.38	0.42	0.46	0.12**
	Grain	0.30	0.41	0.50	0.53	0.56	0.14**	0.18	0.26	0.39	0.43	0.47	0.13**
	Stover	0.02	0.03	0.05	0.11	0.23	0.09**	0.02	0.02	0.04	0.07	0.13	0.05**
K	Plant	0.73	0.96	1.18	0.86	0.90	n.s.	0.61	0.83	1.08	1.13	1.46	n.s.
	Grain	0.31	0.36	0.35	0.43	0.38	n.s.	0.33	0.32	0.32	0.37	0.48	0.08*
	Stover	0.45	0.59	0.46	0.68	0.76	n.s.	0.50	0.40	0.39	0.89	0.58	0.28**
		ppm											
Na	Plant	70	45	101	91	69	35*	66	45	58	40	53	n.s.
	Grain	20	15	19	26	79	n.s.	20	30	14	14	15	n.s.
	Stover	332	133	265	331	483	n.s.	167	50	71	61	105	65**
		%											
Ca	Plant	0.12	0.16	0.22	0.22	0.28	n.s.	0.14	0.16	0.22	0.18	0.24	0.06*
	Grain	0.03	0.03	0.04	0.05	0.07	0.03**	0.03	0.02	0.03	0.03	0.04	0.01**
	Stover	0.14	0.14	0.24	0.47	0.56	0.26*	0.11	0.15	0.17	0.20	0.23	0.06**
Mg	Plant	0.16	0.15	0.20	0.23	0.25	0.06*	0.16	0.16	0.19	0.17	0.20	n.s.
	Grain	0.14	0.16	0.17	0.17	0.19	n.s.	0.12	0.13	0.15	0.16	0.17	0.03**
	Stover	0.12	0.11	0.14	0.25	0.27	0.13**	0.12	0.12	0.10	0.11	0.11	n.s.
		ppm											
Fe	Plant	70	73	85	87	102	n.s.	40	52	51	67	56	n.s.
	Grain	44	42	46	48	53	6**	42	45	39	46	47	n.s.
	Stover	77	78	70	88	76	n.s.	79	74	83	71	90	n.s.

(continued)

TABLE 25. (continued)

Chemical element	Type of sample	Continued sludge applications						Terminated sludge applications					
		Sludge and Water Treatments											
		H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		ppm											
Mn	Plant	50	52	36	29	50	15*	40	43	45	40	33	7*
	Grain	72	69	34	55	83	n.s.	61	61	62	49	39	n.s.
	Stover	73	60	32	42	78	24*	43	67	55	50	25	n.s.
Zn	Plant	35	33	102	101	166	73**	29	36	58	72	92	26**
	Grain	48	59	80	94	110	27**	37	51	64	67	89	23**
	Stover	20	20	70	170	269	72**	13	26	48	83	106	56**
Cd	Plant	0.29	0.40	2.60	4.12	5.09	2.92**	0.22	0.32	1.53	3.25	5.50	2.83**
	Grain	0.10	0.63	1.27	2.26	2.96	1.39**	<0.06	0.15	0.70	1.17	2.39	1.42**
	Stover	0.63	0.43	2.93	7.68	10.51	4.21**	0.30	0.48	1.84	5.12	5.67	3.79**
Cu	Plant	5.9	5.4	7.5	7.9	9.9	2.2*	5.9	6.3	6.6	6.2	7.9	n.s.
	Grain	5.4	5.1	5.6	5.7	7.2	1.1*	4.9	5.0	5.2	5.0	5.9	n.s.
	Stover	2.9	2.1	3.6	5.8	9.0	2.3**	2.6	2.6	2.3	2.8	4.2	1.0*
Ni	Plant	1.2	2.4	1.3	3.3	7.3	2.3**	3.2	1.6	1.5	1.8	2.5	n.s.
	Grain	<0.6	1.3	1.8	4.0	19.3	10.3**	<0.6	<0.6	0.7	0.7	1.9	1.0**
	Stover	<0.6	<0.6	0.9	1.9	7.1	0.9**	1.0	0.7	<0.6	0.7	1.6	0.7*
Cr	Plant	1.29	2.41	0.80	2.14	1.16	n.s.	1.98	1.72	1.03	1.48	2.78	n.s.
	Grain	0.44	0.58	0.83	0.60	1.16	n.s.	0.65	1.00	0.60	0.62	0.60	n.s.
	Stover	<0.13	<0.13	<0.13	<0.13	<0.13		<0.13	<0.13	<0.13	<0.13	<0.13	
Pb	Plant	0.6	<0.6	<0.6	0.6	0.7	n.s.	0.8	0.7	0.8	<0.6	0.8	n.s.
	Grain	<0.6	<0.6	<0.6	<0.6	<0.6		<0.6	<0.6	<0.6	<0.6	0.6	n.s.
	Stover	0.8	1.3	1.9	1.8	2.3	n.s.	1.4	0.7	1.9	1.6	2.2	n.s.

a/ Dry weight basis.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

levels were not excessively high. Where sludge applications had been continued through 1976, Mn concentrations were lower in whole green plants and stover of wheat on plots treated with intermediate rates of sludge as compared to tissues from control and maximum-treated plots. Where sludge had not been applied since 1972, whole plants from plots formerly treated with maximum sludge rates had significantly lower Mn concentrations than those from other plots. Concentrations of Zn and Cd were increased in all tissues by sludge treatments regardless of the time at which sludge applications had been terminated on plots. But levels of Zn and Cd in grain were lower where sludge applications had been terminated in 1972 as compared to 1976. Where sludge applications had been continued through 1976, Cu concentrations were increased in all wheat tissues by maximum sludge treatments. Plants from these plots also contained higher levels of Ni than those from control plots. Concentrations of Ni in wheat grain from long-term maximum-sludge-treated plots were significantly higher than in whole green plants and stover, but not in grain from plots treated with maximum rates only to 1972. Sludge applications did not significantly affect concentrations of Cr and Pb in wheat plant tissues.

Concentrations of 0.1 N HCl Extractable P in Soils and Inorganic Fractions of Sludge and Soil P--

Concentrations of 0.1 N HCl extractable P are presented in Table 26. Sludge applications significantly increased extractable P each year and for as long as sludge was applied high levels were maintained in maximum-sludge-treated plots. Where sludge applications were terminated in 1972, extractable P levels in maximum treated soil did not show a significant decline during the last two years in which such measurements were made. When soybeans suffered from a severe P toxicity in 1972, extractable P levels were much increased in the 30 to 46 cm depth of soil as compared to the previous year and in following years. Thus, soybeans never recovered from the P toxicity condition produced during the seedling stage because available P levels were exceedingly high throughout the root zone. After soybean growth was stopped or reduced by P toxicity, concentrations of P in various inorganic fractions were determined in the two sludges which were applied on plots during 1971 by the Chang and Jackson procedure as modified by Peterson and Corey (1966). Digested sludge from the Calumet wastewater treatment plant had higher contents of saloid-P and Al-P and lower contents of Ca-P and Fe-P than similar kinds of sludge from the wastewater treatment plant at Stickney (Table 27). Reductant soluble phosphate in the two sludges were not significantly different. Neither was organic-P concentrations different in the two sludges as determined by differences between total P and total inorganic-P derived by summing concentrations in the several fractions. The procedure used to fractionate inorganic-P concentrations in sludge was used to obtain the results for soil inorganic-P fractions as shown in Table 28. Maximum sludge applications increased Al-P and Fe-P concentrations in soils but had only minimal effects on levels of other inorganic-P fractions. Although maximum sludge applications apparently increased concentrations of organic-P in the soil, the percentage of total P in organic forms appeared to increase very little in soils. Except for an unusually high level of organic-P in the soil plow-layer, the P fractionation results provided little information for explaining why the P toxicity condition was more severe in 1972 than in previous and succeeding years.

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TABLE 26. SOIL CONCENTRATIONS OF 0.1 N HCl EXTRACTABLE P IN PLOTS CONTINUOUSLY PLANTED TO SOYBEANS AND IRRIGATED WITH DIGESTED SEWAGE SLUDGE OR WATER WITH COMPARISONS TO NON-IRRIGATED CONTROL PLOTS.

		Continued sludge applications						Terminated sludge applications					
		Sludge and water treatments											
Depth cm	Year	H_2O	0	1/4 Max	1/2 Max	Max	LSD	H_2O	0	1/4 Max	1/2 Max	Max	LSD
		ppm											
0-15	1971	40.5	45.4	255.4	571.9	945.1	498.2**	58.5	42.5	199.2	541.0	846.7	485.0**
	1972	46.5	47.6	317.3	772.9	982.1	143.9**	37.4	50.1	320.1	550.2	1030.4	261.9**
	1973	50.9	58.5	355.2	655.9	1019.8	340.4**	18.6	46.0	239.5	466.0	955.2	100.0**
	1974	92.9	109.2	261.6	518.5	1180.8	444.8**	38.0	102.3	233.8	556.4	950.9	354.7**
15-30	1973	24.10	34.97	71.63	167.77	228.10	128.61**	16.37	21.90	62.60	101.03	198.10	96.78**
	1974	23.0	32.6	81.5	148.8	157.9	85.9*	21.0	27.3	70.0	175.2	226.5	77.7**
30-46	1971	10.8	12.6	15.0	16.4	18.7	n.s.	17.1	14.6	15.4	16.0	17.4	n.s.
	1972	38.1	29.1	31.6	56.1	72.8	23.6**	50.5	24.1	37.1	58.5	89.6	38.5*
	1973	15.2	18.2	16.6	21.8	24.7	n.s.	21.5	24.5	22.8	22.0	23.6	
	1974	19.1	21.9	19.1	34.0	32.1	11.7*	27.5	30.1	29.1	27.8	26.8	
61-76	1973	11.6	22.9	20.8	26.8	18.1		20.9	17.1	21.3	14.0	22.2	
	1974	25.6	31.3	40.1	38.2	29.7		17.0	34.2	57.9	28.3	28.0	

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 27. TOTAL AND FRACTIONS OF INORGANIC PHOSPHORUS IN DIGESTED SLUDGE PRODUCED AT THE CALUMET AND STICKNEY WASTEWATER TREATMENT PLANTS IN CHICAGO DURING 1971.a/

Treatment plant	Sample date (Julian)	Saloid-P	Ca-P	Al-P	Fe-P	Red. Sol.-P	Total inorg. -P fractions	Total inorg. -P conc. HCl	Total -P ash 240°C Conc. HCl	Org -P by difference b/	Org -P %
Stickney	1167	797	535	2660	23432	2473	29897	spilled	36326	6,429	17.7
	1174	580	759	3303	19910	3190	27742	32715	35801	8,059	22.5
	1181	688	626	3347	17280	2828	24697	29818	32044	7,275	22.7
	1196	616	498	2498	20001	2486	26099	29250	33137	7,038	21.2
	1211	580	620	2742	19636	2387	25965	30308	33646	7,681	22.8
	$\bar{x}$	652	608	2910	20052	2673	26880	30523	34191	7,296	21.3
Calumet	1274	2226	335	6853	7997	6158	23569	27093	30636	7,067	23.1
	1294	4397	270	7455	10170	2627	24919	25066	33307	8,388	25.2
	1306	3672	250	7803	10206	2801	24732	29574	34588	9,856	28.5
	1317	4409	252	8417	9915	2387	25380	32044	35192	9,812	27.9
	1327	5390	288	8117	10758	2693	27246	32044	35713	8,467	23.7
	$\bar{x}$	4019	279	7729	9809	3333	25169	29164	33887	8,718	25.7
	LSD	2598**	233**	1624**	6441**	n.s.		n.s.	n.s.	n.s.	

a/ Dry weight basis in ppm.
b/ Org. -P = Total P (ash 240°C) - Total inorg. -P fractions.
** Significant at .01 level of probability.

TABLE 28. TOTAL AND FRACTIONS OF INORGANIC PHOSPHORUS IN BLOUNT SILT LOAM SOILS WITH AND WITHOUT PHOSPHORUS FERTILIZER AND DIGESTED SLUDGE APPLICATIONS.[a/]

Sludge treatment mt/ha b/	Fertilizer treatment Kg P/ha	Year	Saloid-P	Ca-P	Al-P	Fe-P	Red. sol.-P	Total inorg. -P fractions	Total P HCl/HF	Org. -P by difference	Org. P %
0	0	1971	15	22	81	154	163	435	601	166	28%
		1972	14	20	83	171	148	436	580	144	25%
		1973	29	9	88	179	233	538	606	68	11%
		1974	48	14	106	163	213	543	618	75	12%
		1975	45	20	91	176	215	547	636	89	14%
		1976	28	16	94	198	179	515	630	115	18%
Maximum	0	1971	73	56	447	949	332	1858	2286	428	19%
		1972	63	25	494	1479	218	2278	2967	689	23%
		1973	66	44	347	1136	225	1818	2161	343	16%
		1974	45	52	338	1027	308	1770	2332	562	24%
		1975	58	26	395	1207	254	1940	2572	632	25%
		1976	51	107	552	1518	294	2522	2895	373	12%
0	118	1971	25	25	107	145	151	454	542	88	16%
		1972	15	29	65	187	133	429	517	88	15%
		1973	39	12	119	184	194	548	609	61	10%
		1974	39	19	126	176	140	533	630	97	15%
		1975	33	38	130	170	197	568	657	89	14%
		1976	24	21	145	217	214	621	706	85	12%
Maximum	118	1971	63	105	472	1119	327	2087	2471	384	16%
		1972	43	24	470	1074	202	1942	2733	791	29%
		1973	60	42	410	1381	248	2125	2544	419	16%
		1974	64	101	482	1129	425	2201	2734	533	19%
		1975	63	32	462	1650	248	2455	3143	688	22%
		1976	80	167	778	2753	434	4212	4582	370	8%

a/ Dry weight basis of 0 to 15 cm depth of soil in ppm.
b/ See Table 17 for sludge application rates.

CONTINUOUS CORN ON PLOTS OF STRIP-MINE SPOIL MATERIAL

General Description

In the spring of 1973 a continous corn study was established on newly graded strip-mine spoil banks in Fulton County. For this study, sludge loading rates, application methods, replication of treatments, sample collection and handling, etc. were similar to the continuous study established in 1968 on the Northeast Agronomy Research Center, as previously described in this report. The main difference between the two studies was that the sludge used in Fulton County was pumped from holding reservoirs where the digested sludge barged from the Southwest wastewater treatment plant in Chicago was stored until applied on land. Major objectives of the study were to assess the value of sludge for improving strip-mine spoil materials for profitable row-crop production as compared to more conventional fertilizer practices and to compare uptake of inorganic elements by corn grown on sludge-amended strip-mine silty clay loam materials as compared to their concentrations in similar tissues from sludge-amended Blount silt loam soil. Before plowing each spring, 336-, 224-, and 112-kg/ha of N, P, and K, respectively, were applied on control plots.

Discussion of Results

Loading Rates of Sludge and Sludge-borne Constituents--

Concentrations of several constituents of sludge and amounts of sludge-borne constituents annually applied on strip-mined spoil material are shown in Tables 29 and 30. After the first year sludge solids averaged about 4% and during the 5 year period accumulative loading rates totaled about 248 mt/ha. During the last 4 years, more than 13 mt/ha of N was applied, of which about 40% was NH_4-N. On a dry weight basis the sludge contained about 3% P and thus over the 5 years more than 7 mt/ha was applied on maximum-sludge-treated plots. Within the same period, less than 1.5 mt/ha of K was applied, but, compared to normal soil, strip-mined spoil material contains high concentrations of available K. Thus, the imbalance between N and K would be lower on strip-mine spoil than on normal soils where sludge is utilized as an amendment. High amounts of Fe and several other heavy metals were applied as constituents of sludge as compared to amounts generally present in soils. However, strip-mine spoil materials often contain higher amounts of some heavy metals than soils, especially if black-shale layers were mixed with other overburden materials during the mining operations.

Changes in Chemical Properties of Strip-mine Spoil Materials--

In Table 31, total and 0.1 N HCl extractable concentrations of several elements, along with pH, in control and sludge-amended plots on strip-mine spoil are shown. In the beginning of the study, control plots on strip-mine spoil contained less than 50% as much N in the surface as most soils and only about 10% as much organic-C as generally found in low organic matter soils. By the beginning of the third year, sludge application had increased total N and organic-C levels in soils, so that during the last year of the study concentrations of these elements in the surface of maximum-sludge-treated spoil were equivalent to those found in surface of soils developed under forest vegetation. There was a trend toward higher organic-C levels in the

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TABLE 29. CONCENTRATIONS AND TOTAL ANNUAL AMOUNTS OF SEVERAL CONSTITUENTS CONTAINED AT RELATIVELY HIGH CONCENTRATIONS IN SLUDGES APPLIED ON PLOTS OF STRIP-MINE SPOIL MATERIAL PLANTED TO CORN.

Year	Solids %	Total N	NH_4-N	P	K	Na	Ca	Mg	Fe
				Annual means					
	mg/l (wet wt.)								
1974	4.18	2228	1008	1847	188	102	1413	511	2025
1975	4.21	2008	977	905	216	104	1380	554	2370
1976	3.90	1997	905	1613	218	98	1380	554	2370
1977	4.55	2312	832	1510	153	57	1467	589	2262
				Total amounts applied annually					
	mt/ha	kg/ha							
1973	11.9								
1974	51.0	2831	1281	2347	239	130	1796	649	2573
1975	49.7	3062	1490	1380	329	158	2104	845	3614
1976	57.1	3045	1380	2460	332	150	2017	829	3701
1977	78.0	4113	1480	2686	272	101	2610	1048	4024

TABLE 30. CONCENTRATIONS AND TOTAL ANNUAL AMOUNTS OF SEVERAL METALS IN SLUDGES APPLIED ON PLOTS OF STRIP-MINED SPOIL MATERIALS PLANTED TO CORN.

Year	Mn	Zn	Cd	Cu	Ni	Cr	Pb	As	Se	Sb	Hg	Ag
	Annual means, mg/l											
1974	24	201	16.8	69	13.1	132	52					
1975	20	166	11.6	61	15.8	135	49					
1976	20	182	11.5	65	17.0	142	49					
1977	17	267	15.9	76	21.6	37	61	1.22	0.08	0.07	0.03	0.005
	Total amounts applied annually kg/ha											
1974	30	255	21	88	17	168	66					
1975	30	253	18	93	24	206	75					
1976	31	278	18	99	26	216	75					
1977	30	475	28	135	38	66	108	2.2	0.14	0.12	0.06	0.009

TABLE 31. TOTAL N, ORGANIC-C, pH, AND TOTAL AND 0.01 N HCl EXTRACTABLE CONCENTRATIONS OF MACRO-ELEMENTS AND MINOR ELEMENTS IN 0 TO 15, 15 TO 30, 30 TO 46, AND 61 TO 76 cm DEPTHS OF STRIP-MINED SPOIL MATERIAL IN PLOTS LOCATED IN FULTON COUNTY, ILLINOIS.a/b/

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
P	0-15	1973	619	651	711	713		171	180	229	253	
		1974	680	584	713	634	88*	230	160	211	183	
		1975	656	789	989	1772	826**	226	323	466	-	
		1976	785	841	1083	1394	431**	274	323	325	524	172**
		1977	893	1020	1448	2146	637**					
	15-30	1973	494	600	583	637		139	186	216	171	
		1974	553	543	556	616		168	128	141	170	
		1975	411	517	436	555	100*	130	137	162	208	
		1976	606	683	601	779		196	339	232	443	
		1977	509	455	510	636						
	30-46	1973	410	445	497	406		180	162	154	123	
		1974	680	584	713	634		214	226	197	195	
		1975	278	285	302	309		179	165	171	148	
		1976	445	334	426	451			238	241	222	
		1977	272	232	248	260						
	61-76	1973	507	482	410	572		153	225	139	174	
		1974	-	-	-	-		-	-	-	-	
		1975	300	277	337	306		145	105		137	
		1976	347	341	557	438		213	174		232	
		1977	651	554	610	610						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates: 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total %					0.1 N HCl Extr. mg/kg				
K	0-15	1973	2.05	2.08	2.01	2.03		266	255	250	248	
		1974	1.85	1.72	1.88	1.77		268	252	245	243	
		1975	1.99	1.94	1.98	1.99		262	253	240	246	
		1976	1.95	1.94	1.94	1.99		266	246	210	219	
		1977	1.98	1.96	1.92	1.92						
	15-30	1973	1.83	2.04	1.94	1.96		230	250	236	283	
		1974	1.74	1.73	1.72	1.71		241	228	209	210	
		1975	2.11	2.01	2.09	2.06	0.17*	250	241	236	235	
		1976	2.05	1.96	2.01	1.94		290	268	250	247	
		1977	1.60	1.73	1.67	1.66						
	30-46	1973	2.07	2.09	2.03	2.08		231	246	230	254	
		1974	1.85	1.72	1.88	1.77		222	230	230	208	
		1975	2.03	2.01	2.00	1.99		261	263	250	260	
		1976	1.89	1.98	1.91	1.96		258	280	266	281	
		1977	1.81	1.98	1.83	1.92						
	61-76	1973	2.02	2.03	1.93	1.93		226	251	216	231	
		1974	-	-	-	-		-	-	-	-	
		1975	2.03	1.95	1.96	2.04		261	256	261	268	
		1976	1.89	2.00	1.87	1.91		276	280	269	283	
		1977	1.94	1.84	1.96	1.87						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
Na	0-15	1973	7250	7342	7447	7577		64	64	71	66	
		1974	6772	6645	7296	7423		44	47	49	65	
		1975	8712	8071	8892	6544		72	79	72	84	
		1976	6959	6696	7425	5938		68	63	67	70	
		1977	7036	6079	5478	6616						
	15-30	1973	6679	6547	7480	7327		70	61	78	66	
		1974	7211	7191	7297	7654		56	56	70	62	
		1975	7861	7923	8507	9444		71	79	76	75	
		1976	7065	6482	6806	7353		85	76	84	86	
		1977	5816	6501	7642	7213	1160**					
	30-46	1973	7831	7277	7513	7705		93	54	86	70	
		1974	6772	6645	7296	7423		57	58	72	63	
		1975	8841	7837	8343	8517		73	80	82	72	
		1976	7595	7255	7700	7858		98	104	106	98	
		1977	5343	5715	5445	5507						
	61-76	1973	7349	6521	7812	6998		74	77	76	75	
		1974	-	-	-	-		-	-	-	-	
		1975	9519	8251	8816	8785		73	70	97	72	
		1976	7009	7482	6907	7659		80	78	102	80	
		1977	6674	5816	6537	6431						

(continued)

TABLE 31. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	 1/4 Max	 1/2 Max	 Max	 LSD	 0	 1/4 Max	 1/2 Max	 Max	 LSD
			----Total----					----0.1 N HCl Extr.----				
			----%									
Ca	0-15	1973	0.80	0.80	0.79	0.93		0.53	0.83	0.72	0.56	
		1974	1.03	0.91	1.10	1.06		0.97	0.98	0.97	0.91	
		1975	1.16	1.19	0.89	1.10		1.03	1.14	0.73	0.92	
		1976	1.02	1.03	1.08	1.02						
		1977	1.12	1.24	1.22	1.08						
	15-30	1973	0.96	0.96	1.21	1.00			0.85	0.84	0.95	
		1974	0.95	1.00	1.08	1.19		0.79	0.96	0.95	0.96	
		1975	1.38	1.25	1.00	0.98		1.00	0.96	0.79		
		1976	1.26	1.24	1.28	1.03			0.77		0.88	
		1977	1.08	1.06	0.90	0.72						
	30-46	1973	1.20	0.99	1.23	0.90			0.74	0.68	0.78	
		1974	1.03	0.91	1.10	1.06		0.88	0.91	0.83	0.94	
		1975	1.22	1.33	1.18	0.78		0.96	1.03	0.91	0.86	
		1976	1.28	1.02	1.10	1.02		0.99		0.96	0.89	
		1977	0.91	0.98	0.94	0.93						
	61-76	1973	0.93	0.89	0.85	0.93		0.64		0.72	0.91	
		1974	-	-	-	-		-	-	-	-	
		1975	0.85	1.33	1.43	1.11			1.27	1.24		
		1976	0.74	1.06	1.11	0.92		0.90				
		1977	1.11	1.07	1.00	1.59						
Mg	0-15	1973	0.77	0.91	0.78	0.74		0.15	0.27	0.18	0.14	
		1974	0.81	0.77	0.81	0.70		0.23	0.29	0.28	0.27	
		1975	0.84	0.91	0.92	0.90		0.23	0.34	0.20	0.23	
		1976	0.69	0.68	0.73	0.75		0.28	0.32	0.30	0.29	
		1977	0.81	0.82	0.82	0.85						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			%									
Mg	15-30	1973	0.46	0.51	0.56	0.55		0.26	0.29	0.21	0.32	
		1974	0.85	0.89	0.89	0.87		0.31	0.31	0.35	0.39	
		1975	0.75	0.98	0.90	0.93		0.32	0.45	0.26	0.40	
		1976	0.81	0.78	0.69	0.69		0.32	0.25	0.32	0.23	
		1977	0.62	0.68	0.48	0.61						
	30-46	1973	0.63	0.45	0.63	0.71		0.33	0.34	0.36	0.33	
		1974	0.81	0.77	0.81	0.70		0.28	0.25	0.24	0.34	
		1975	0.96	0.92	0.85	0.62		0.29	0.32	0.28	0.30	
		1976	0.85	0.84	0.80	0.84		0.32	0.34	0.33	0.32	
		1977	0.78	0.83	0.88	0.83						
	61-76	1973	0.49	0.49	0.46	0.47		0.31	0.30	0.35	0.36	
		1974	-	-	-	-		-	-	-	-	
		1975	0.69	0.76	0.98	1.08		0.27	0.34	0.43	0.40	
		1976	0.75	0.88	0.79	0.76		0.28	0.39	0.44	0.42	
		1977	0.78	0.75	0.56	0.91						
Fe	0-15	1973	2.94	2.73	3.07	3.07		0.12	0.11	0.13	0.14	
		1974	3.55	3.69	3.98	3.22		0.13	0.11	0.12	0.12	
		1975	3.06	3.25	3.27	3.27		0.14	0.14	0.12	0.15	
		1976	3.56	3.66	4.21	3.62		0.18	0.14	0.18	0.19	
		1977	3.48	3.66	3.30	3.68						
	15-30	1973	2.47	3.01	3.21	2.97		0.21	0.12	0.23	0.19	
		1974	3.44	3.57	3.45	3.52		0.13	0.11	0.22	0.14	
		1975	3.67	3.42	3.52	3.43		0.20	0.10	0.10	0.14	
		1976	3.60	3.52	3.94	3.59		0.22	0.11	0.18	0.17	
		1977	3.50	3.40	3.67	3.40						

(continued)

TABLE 31. (continued)

Param-eter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			%									
Fe	30-46	1973	3.05	3.56	3.45	3.25		0.28	-	0.46	0.42	
		1974	3.55	3.69	3.99	3.22		0.12	0.12	0.18	-	
		1975	3.15	3.39	3.12	2.41		0.17	0.09	0.15	0.17	
		1976	3.45	3.76	3.83	3.67		0.19	0.18	0.30	0.31	
		1977	3.40	3.34	3.23	3.67						
	61-76	1973	3.09	3.36	2.79	2.79		0.19	0.17	0.18	0.15	
		1974	-	-	-	-		-	-	-	-	
		1975	2.53	2.95	3.12	2.83		0.15	0.13	0.14	0.14	
		1976	3.41	3.70	3.96	—		0.29	0.24	0.29	0.27	
		1977	3.67	3.43	3.82	3.66						
			mg/kg									
Mn	0-15	1973	500	642	701	618	134*	289	284	396	342	
		1974	633	616	718	724		453	436	487	452	
		1975	620	821	634	718		393	444	370	447	
		1976	643	646	786	688		443	470	524	468	
		1977	620	750	780	699						

(continued)

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TABLE 31. (continued)

Parameter	Depth cm	Year	Total 0	Total 1/4 Max	Total 1/2 Max	Total Max	Total LSD	0.1 N HCl Extr. 0	0.1 N HCl Extr. 1/4 Max	0.1 N HCl Extr. 1/2 Max	0.1 N HCl Extr. Max	0.1 N HCl Extr. LSD
			mg/kg									
Mn	15-30	1973	748	756	701	684		600	455	503	528	
		1974	585	721	686	646		298	328	343	314	
		1975	632	738	774	749		405	412	352	477	
		1976	658	653	802	675		431	341	521	462	
		1977	602	693	719	649						
	30-46	1973	668	644	738	704		433	371	579	556	
		1974	633	616	719	724		416	493	481	450	
		1975	688	749	709	684		402	366	404	435	
		1976	732	713	762	748		445	412	439	472	
		1977	632	616	660	625						
	61-76	1973	715	836	631	715		468	602	472	543	
		1974	-	-	-	-		-	-	-	-	
		1975	669	812	836	695		379	492	553	409	
		1976	525	718	754	707		379	492	553	409	
		1977	752	792	865	775						
Zn	0-15	1973	62	67	64	64		3.4	4.3	3.7	3.6	
		1974	51	60	68	70	12*	4.5	6.5	9.1	10.3	1.7**
		1975	55	76	113	194	98*	3.9	20.8	50.3	114.3	73.1**
		1976	65	98	118	157	43**	9.5	30.6	43.3	82.0	31.6**
		1977	68	105	156	240	32**					
	15-30	1973	62	74	71	64		2.4	3.2	3.1	2.1	
		1974	61	62	66	70		3.7	5.7	5.5	6.0	
		1975	55	60	67	71		3.8	6.2	8.6	12.3	6.0**
		1976	57	58	67	69		3.2	5.1	4.8	6.9	
		1977	52	63	49	74						

(continued)

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TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
Zn	30–46	1973	67	76	71	63		2.7	3.0	3.1	2.5	
		1974	51	60	68	70		2.6	3.7	4.5	5.7	
		1975	57	54	58	56		2.6	3.6	4.9	6.8	2.5*
		1976	51	59	61	57		3.8	5.1	5.8	8.4	3.3**
		1977	52	56	60	60						
	61–76	1973	67	66	64	60		3.1	3.6	3.6	2.9	
		1974	–	–	–	–		–	–	–	–	
		1974	54	49	52	52		3.5	3.1	3.2	4.7	
		1976	56	61	61	59		4.4	6.5	5.1	6.1	1.4*
		1977	59	51	43	55						
Cd	0–15	1973	0.7	0.7	0.9	0.8		<0.25	<0.25	<0.25	<0.25	
		1974	0.5	0.6	1.1	1.2		0.27	0.42	0.58	0.80	0.24**
		1975	<0.25	1.2	4.0	7.56	4.2*	<0.25	1.34	3.41	8.15	
		1976	0.6	2.1	4.0	7.2	2.8**	0.64	2.45	3.26	6.27	2.31**
		1977	1.2	3.8	7.5	11.2	2.0**					
	15–30	1973	0.9	0.8	1.1	1.0		<0.25	<0.25	0.26	<0.25	
		1974	0.4	0.7	0.5	1.1		<0.25	0.34	0.27	0.30	
		1975	0.4	0.6	0.5	1.0		<0.25	<0.25	<0.25	0.51	0.26*
		1976	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25		
		1977	<0.25	<0.25	0.42	1.06						
	30–46	1973	0.6	0.5	1.0	0.6		<0.25	<0.25	0.28	0.28	
		1974	<0.25	<0.25	<0.25	0.30		<0.25	<0.25	<0.25	0.28	
		1975	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	
		1976	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	
		1977	<0.25	<0.25	<0.25	<0.25						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			--------Total--------					--------0.1 N HCl Extr.--------				
			--------mg/kg--------									
Cd	61-76	1973	1.3	1.0	0.8	0.8		<0.25	0.28	<0.25	<0.25	
		1974	-	-	-	--		-	-	-	-	
		1975	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	
		1976	<0.25	<0.25	<0.25	<0.25		<0.25	<0.25	<0.25	<0.25	
		1977	0.33	0.25	<0.25	<0.25						
Cu	0-15	1973	20	18	21	21		3.3	2.7	3.3	3.7	
		1974	26	35	32	29		3.6	5.3	5.6	6.8	2.1*
		1975	26	49	65	70	29*	2.3	7.8	19.4	39.6	26.1*
		1976	29	40	45	64	17**	6.8	14.6	19.5	32.6	13.0**
		1977	31	48	69	106	21**					
	15-30	1973	20	23	23	21		3.3	3.9	4.4	4.9	
		1974	28	27	30	30		4.4	4.6	4.8	4.9	
		1975	35	26	30	35		2.5	1.5	2.8	4.2	
		1976	24	27	27	28		1.8	3.3	2.6	4.5	
		1977	22	26	31	35	9*					
	30-46	1973	20	19	19	24		3.7	4.2	4.5	5.2	
		1974	26	35	32	29		3.6	3.2	4.2	5.1	
		1975	30	33	40	36		1.1	1.2	2.1	2.9	
		1976	24	27	27	21		1.7	1.8	2.6	3.6	
		1977	28	31	23	22						
	61-76	1973	23	21	19	20		4.8	5.5	5.6	4.2	
		1974	-	-	-	-		-	-	-	-	
		1975	26	25	24	29		1.5	1.6	1.6	1.9	
		1976	24	26	26	22		1.9	2.6	2.2	2.3	
		1977	28	22	25	23						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates									
			0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
Ni	0-15	1973	57	52	56	55		4.4	3.9	5.4	4.8	
		1974	65	63	67	58		5.4	5.4	5.7	6.0	
		1975	43	50	57	57		4.4	5.7	8.3	11.3	4.2**
		1976	43	47	47	49		5.7	7.5	8.9	10.8	2.4**
		1977	38	41	45	54	5**					
	15-30	1973	57	52	56	55		4.9	4.0	4.9	4.7	
		1974	56	54	59	53		5.3	6.0	6.0	5.7	
		1975	39	35	37	37		3.1	3.8	3.6	4.4	
		1976	45	41	45	42		3.7	4.1	5.5	4.2	
		1977	39	38	29	38						
	30-46	1973	52	45	54	54		4.6	4.4	4.7	4.9	
		1974	65	63	67	58						
		1975	39	36	36	36		4.3	3.7	4.7	5.1	
		1976	41	41	40	38		5.0	4.7	5.5	6.0	
		1977	38	35	35	36						
	61-76	1973	54	54	52	52		4.7	5.0	4.6	4.8	
		1974	-	-	-	-		-	-	-	-	
		1975	35	59	35	33		4.3	5.2	4.9	4.8	
		1976	40	42	41	41		2.2	1.4	2.0	2.0	
		1977	42	36	41	36						
Cr	0-15	1973	63	68	71	69		0.5	0.4	0.4	0.5	
		1974	54	56	65	56		0.6	0.9	1.1	1.5	
		1975	68	73	96	124	35**	1.0	5.3	9.6	26.2	
		1976	72	93	101	136	30**	2.0	6.5	8.9	17.8	7.4**
		1977	70	97	142	189	23**					

(continued)

TABLE 31. (continued)

Param-eter	Depth cm	Year	Sludge application rates 0	 1/4 Max	 1/2 Max	 Max	 LSD	 0	 1/4 Max	 1/2 Max	 Max	 LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
Cr	15-30	1973	59	63	67	77		0.8	0.7	0.8	0.9	
		1974	55	54	46	58		1.2	1.3	1.4	1.6	
		1975	58	55	58	62		0.9	1.1	1.4	2.2	
		1976	73	68	69	69		0.9	0.9	1.8	2.3	
		1977	64	63	70	75						
	30-46	1973	62	65	68	64		1.3	0.6	1.1	1.0	
		1974	54	56	65	58		0.6	1.0	1.1	1.2	
		1975	55	58	60	60		0.6	0.7	0.6	1.1	
		1976	71	61	70	62		2.5	2.5	2.5	3.2	
		1977	69	64	61	61						
	61-76	1973	64	66	59	62						
		1974	-	-	-	-		-	-	-	-	
		1975	59	53	67	57		2.0	1.4	1.5	1.5	
		1976	58	59	68	59		2.2	1.4	2.0	2.0	
		1977	70	69	78	65						
Pb	0-15	1973	19	23	18	20		3.4	2.7	3.6	3.5	
		1974	18	19	21	21		4.1	5.5	5.9	6.1	1.4*
		1975	23	28	35	47	15*	6.1	8.2	13.7	26.3	
		1976	17	27	32	43	15**	6.8	11.8	13.5	24.5	7.2**
		1977	29	38	50	76	11**					
	15-30	1973	17	19	19	21		3.6	3.2	3.5	3.6	
		1974	23	25	23	25		5.4	4.5	5.9	5.4	
		1975	25	22	26	24		4.9	5.8	5.5	7.5	
		1976	8	17	15	18		4.4	2.7	3.7	5.7	
		1977	15	16	18	21						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD	0	1/4 Max	1/2 Max	Max	LSD
			Total					0.1 N HCl Extr.				
			mg/kg									
Pb	30-46	1973	20	25	19	20		3.5	2.8	4.1	4.0	
		1974	18	19	21	21		6.9	6.9	8.5	8.7	
		1975	25	25	25	26		3.6	4.1	3.5	3.4	
		1976	15	14	12	13		6.5	6.2	5.6	6.8	
		1977	18	18	22	19						
	61-76	1973	20	20	19	22		3.4	3.4	3.7	4.4	
		1974	-	-	-	-		-	-	-	-	
		1975	20	20	20	20		5.0	4.0	5.1	5.4	
		1976	16	16	16	17		6.0	4.8	5.5	6.6	
		1977	19	23	24	20						
			%									
Total N	0-15	1973	0.05	0.04	0.05	0.06						
		1974	0.06	0.04	0.05	0.05						
		1975	0.05	0.05	0.07	0.11	0.04*					
		1976	0.06	0.08	0.08	0.12	0.02**					
		1977	0.07	0.08	0.10	0.15	0.02**					
	15-30	1973	0.03	0.03	0.03	0.03						
		1974	0.04	0.04	0.04	0.03						
		1975	0.03	0.03	0.03	0.04						
		1976	0.04	0.04	0.04	0.05						
		1977	0.05	0.04	0.05	0.06						
	30-46	1973	0.04	0.04	0.03	0.04						
		1974	0.04	0.04	0.04	0.03						
		1975	0.04	0.03	0.04	0.03						
		1976	0.04	0.04	0.04	0.04						
		1977	0.05	0.04	0.04	0.04						

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			--------------------%--------------------				
Total N	61-76	1973	0.03	0.03	0.03	0.03	
		1974	-	-	-	-	
		1975	0.03	0.03	0.03	0.03	
		1976	0.04	0.03	0.03	0.03	
		1977	0.04	0.04	0.04	0.04	
Org.-C	0-15	1973	0.12	0.16	0.18	0.17	
		1974	0.25	0.27	0.30	0.33	
		1975	0.24	0.30	0.52	0.94	0.48*
		1976	0.33	0.41	0.50	0.76	0.23**
		1977	0.41	0.48	0.75	1.36	0.26**
	15-30	1973	0.21	0.22	0.19	0.42	
		1974	0.19	0.18	0.15	0.24	
		1975	0.23	0.22	0.20	0.33	
			------------------Units------------------				
pH	0-15	1973	7.8	7.7	8.0	8.0	
		1974	8.0	8.0	8.1	8.1	
		1975	7.8	7.7	7.6	7.5	
		1976	7.7	7.7	7.8	7.6	
		1977	7.2	7.5	7.0	7.3	
	15-30	1974	7.9	7.9	7.8	7.8	
		1975	8.2	8.1	8.0	8.0	
		1976	7.8	7.8	7.8	7.4	
		1977	7.7	7.6	7.6	7.5	

(continued)

TABLE 31. (continued)

Parameter	Depth cm	Year	Sludge application rates 0	1/4 Max	1/2 Max	Max	LSD
			---------------Units-----------------				
pH	30-46	1974	8.0	8.0	7.9	7.8	
		1975	7.9	7.8	7.8	7.8	
		1976	7.8	7.6	7.8	7.7	
	61-76	1974	7.9	7.9	7.8	7.8	
		1975	8.2	8.1	8.0	8.0	
		1976	7.8	7.8	7.8	7.4	
		1977	7.7	7.6	7.6	7.5	

a/ Concentrations are on a dry weight basis.

b/ Digested sludge was applied annually on replicated plots at various rates and control plots were annually treated with a relatively high rate of inorganic fertilizer.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

surface of control plots which might be caused by the return of high amounts of plant residues, but it seems more likely to be due to contamination. By chance three of the four control plots are located adjacent to maximum-sludge-treated plots and the increase of some trace elements in the surface of these control plots indicate some mixing of spoil materials between these plots. Mixing probably occurred as a result of tillage operations. Both total and 0.1 N HCl extractable P concentrations were increased by higher sludge application rates in the surface of strip-mine spoil. Total P levels in strip-mine spoil were not too different from those expected in normal soils and 0.1 N HCl extractable levels in spoil were not very meaningful because the material had pH values greater than 7. Sludge application did not significantly change levels of K, Na, Ca, Mg, Fe, and Mn in strip-mine spoil materials. Levels of these elements in strip-mine spoil did vary somewhat from those found in Blount silt loam soil. As expected concentration of the several elements were uniformly distributed by depth in spoil materials. Total K and Na levels in spoil materials were similar to those in surface of Blount silt loam. Concentrations of Ca, Mg, and Fe were higher and Mn lower in the surface of spoil material than in the surface of Blount silt loam. However, at the 61 to 76 cm depth of Blount silt loam, most total concentrations of these elements, except Ca, were not markedly different than those found in strip-mine spoil. During the last three years of the study, sludge-applications markedly increased total and 0.1 N HCl extractable levels of Zn, Cd, Cu, Cr, and Pb in the surface of strip-mine spoil. Extractable levels of Ni were increased during the last years of the study, but little change was noted in total concentrations. Except for extractable levels of Cd in the 15 to 30 cm depth, and Zn in all depths, concentrations of elements in subsurface depths of spoil were unaffected by sludge applications. In the absence of sludge applications, levels of Zn and Cd were about the same; Cu, Ni, and Cr were higher, and Pb were lower in strip-mine spoil than in the surface of most soils. Although highly variable from year to year, there was no evidence that even maximum sludge applications had caused a significant decrease in soil pH. All treatments, including inorganic fertilizer applications, may have caused an insignificant trend toward a lower pH in the surface of spoil materials.

Yields of Corn Grown on Strip-mine Spoil Material--

As shown in Table 32, corn plant populations varied somewhat from the aim of 50,000 plants/ha, but with a particular year populations were not so different between treatments as to cause a substantial difference in yields. Maximum sludge applications caused significantly higher yields of corn grain in 3 of the 5 years and the 5-year mean yields were also significantly higher. However, the expected increase in corn yields with increased years of applying sludge did not occur. Stover yields were not significantly different as a result of annual sludge applications and, like grain yields, seemed to remain unaffected by accumulative sludge applications.

Changes in Chemical Composition of Corn Plant Tissues--

The data presented in Table 33 shows that, except for Zn and Cd, sludge applications did not consistently cause significant changes in concentrations of those elements selected for determination. In no case was there an indication that accumulative applications of sludge had caused a substantial difference in concentrations of an element in particular tissues of corn.

TABLE 32. PLANT POPULATIONS AND GRAIN AND STOVER YIELDS OF CORN GROWN ON STRIP-MINE SPOIL MATERIAL WITH AND WITHOUT DIGESTED SEWAGE SLUDGE.

Year	Sludge application rates				
	0	¼-Max	½-Max	Max	LSD
	Plant population				
	----------number/ha----------				
1974	46403	51935	50244	45635	
1975	52498	59461	53777	54854	
1976	55466	54854	56389	51626	
1977	49629	51012	51012	54545	
	Grain yields				
	----------mt/ha----------				
1973	1.96	3.44	3.17	3.10	
1974	1.11	1.44	1.74	2.38	0.68*
1975	4.00	4.95	5.41	5.15	
1976	2.99	4.38	4.37	3.81	0.83*
1977	2.37	1.60	2.09	3.00	0.95*
Means	2.48	3.16	3.36	3.49	0.65*
	Stover yields				
	----------mt/ha----------				
1974	2.60	2.78	3.54	4.03	
1975	4.11	3.83	3.76	3.86	
1976	4.09	4.37	4.30	3.78	
1977	3.28	4.00	4.14	4.50	
Means	3.52	3.74	3.94	4.04	

TABLE 33. CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS AND ASH IN CORN PLANT TISSUES FROM PLOTS OF STRIP-MINE SPOIL MATERIAL WITH AND WITHOUT SLUDGE.a/

		Sludge application rates														
		Leaf					Grain					Stover				
Constituent	Year	0	¼-Max	½-Max	Max	LSD	0	¼-Max	½-Max	Max	LSD	0	¼-Max	½-Max	Max	LSD
		%														
N	1973	3.06	2.99	3.01	3.38	0.30**	1.66	1.62	1.68	1.79		0.91	0.89	0.97	1.08	
	1974	2.72	2.89	2.94	2.95	0.20**	2.08	2.12	2.08	1.97		1.40	1.41	1.34	1.56	
	1975	2.92	2.92	2.94	3.04		1.73	1.57	1.61	1.70		1.07	0.86	0.77	0.95	
	1976	2.93	2.82	2.85	2.85		1.45	1.45	1.41	1.51		0.76	0.76	0.69	0.80	
	1977	3.05	3.06	3.11	3.39		1.93	2.16	2.09	2.02		1.58	1.70	1.59	1.52	
P	1973	0.32	0.28	0.27	0.31		0.40	0.29	0.30	0.32		0.15	0.09	0.10	0.11	
	1974	0.58	0.35	0.36	0.35		0.43	0.37	0.37	0.35		0.20	0.13	0.11	0.09	
	1975	0.31	0.30	0.26	0.27		0.33	0.29	0.28	0.30		0.15	0.08	0.07	0.09	0.05**
	1976	0.29	0.27	0.26	0.27		0.29	0.27	0.24	0.24	0.04*	0.11	0.10	0.09	0.10	0.01*
	1977	0.32	0.31	0.33	0.30		0.36	0.36	0.35	0.34		0.14	0.12	0.10	0.09	0.03*
K	1973	1.92	2.41	2.21	2.14		0.44	0.33	0.35	0.34		1.37	1.68	1.68	1.69	
	1974	2.55	2.44	2.48	2.70	0.16*	0.44	0.44	0.44	0.41		1.49	1.11	1.35	1.61	
	1975	1.70	1.64	1.63	1.51		0.51	0.48	0.48	0.49		0.98	1.11	0.96	1.13	
	1976	1.79	1.80	1.72	1.85		0.41	0.40	0.36	0.36	0.04*	1.51	1.59	1.79	1.55	
	1977						0.37		0.32	0.38						
		mg/kg														
Na	1973	33	41	37	26		8.8	9.3	10.0	7.0		24	22	28	32	
	1974	50	49	53	50		8.0	14.0	10.8	15.5		47	52	46	50	
	1975	145	110	107	122		7.8	6.6	5.8	6.0		67	81	90	89	
	1976	30	38	28	32		6.8	5.8	4.2	5.8		24	32	72	114	
	1977	23	22	28	19		3.0		2.2	2.9		36	18	28	22	
		%					mg/kg					%				
Ca	1973	0.61	0.54	0.57	0.52		21	24	26	21		0.29	0.30	0.34	0.37	
	1974	0.54	0.56	0.45	0.59		96	98	84	73		0.09	0.12	0.12	0.13	
	1975	0.48	0.53	0.56	0.53		43	44	47	57		0.20	0.26	0.23	0.27	
	1976	0.68	0.67	0.67	0.85	0.13**	64	66	96	72		0.31	0.32	0.43	0.47	
	1977	0.67	0.68	0.72	0.81							0.36	0.57	0.35	0.53	
		%														
Mg	1973	0.37	0.29	0.29	0.24		0.12	0.09	0.09	0.10		0.17	0.24	0.24	0.19	
	1974	0.50	0.48	0.37	0.36		0.17	0.15	0.13	0.13		0.32	0.35	0.34	0.37	
	1975	0.44	0.49	0.45	0.35		0.15	0.13	0.12	0.13		0.23	0.23	0.21	0.23	
	1976	0.39	0.39	0.38	0.37		0.13	0.12	0.12	0.12		0.28	0.31	0.32	0.37	
	1977	0.40	0.42	0.38	0.33		0.15	0.15	0.15	0.14		0.29	0.31	0.28	0.29	

(continued)

TABLE 33. (continued)

Constituent	Year	Leaf 0	Leaf ¼-Max	Leaf ½-Max	Leaf Max	Leaf LSD	Grain 0	Grain ¼-Max	Grain ½-Max	Grain Max	Grain LSD	Stover 0	Stover ¼-Max	Stover ½-Max	Stover Max	Stover LSD
		mg/kg														
Fe	1973	379	118	120	112		36	30	18	22		138	96	79	107	
	1974	267	147	132	125		24	17	16	17		372	252	200	152	
	1975	118	126	134	119		15	17	17	19	2**	105	71	86	85	
	1976	191	200	196	192		16	17	20	20	3**	240	244	181	195	46*
	1977	155	138	147	146		13	19	21	21		213	444	203	277	
Mn	1973	143	69	73	86	34**	10	7	7	8		58	53	49	59	
	1974	80	91	94	103		8	7	7	6		63	49	54	64	
	1975	58	44	53	60		7	6	5	5		43	39	38	42	
	1976	80	68	80	108	17**	7	5	5	5		68	73	71	74	
	1977	88	80	107	156		10	10	9	9		68	65	63	84	12*
Zn	1973	15	34	43	80	33**	15	19	22	26	6**	5	23	34	36	21**
	1974	13	43	51	72	9**	19	28	33	32	6**	9	43	53	76	24**
	1975	21	74	93	121	16**	18	29	32	37	5**	18	60	70	122	26**
	1976	33	109	124	191	42**	20	32	35	41	5**	12	81	124	176	51**
	1977	33	81	132	200	41**	25	33	39	45	10**	26	77	131	218	61**
Cd	1973	0.34	0.32	0.75	1.49	0.72*	<0.06	0.12	0.12	0.21		0.32	0.36	0.91	1.38	0.78*
	1974	0.29	0.78	1.47	4.06	1.21**	<0.06	0.12	0.18	0.24	0.06**	0.31	1.98	3.21	6.00	1.61**
	1975	0.12	1.84	3.90	7.45	2.55**	0.08	0.16	0.21	0.38	0.09**	0.43	4.88	6.34	14.14	4.24**
	1976	1.42	6.15	8.50	22.59	6.85**	<0.06	0.14	0.46	0.54	0.28**	1.80	12.36	22.85	35.01	7.24**
	1977	1.94	5.60	15.53	28.72	5.97**	0.08	0.21	0.46	0.78	0.19**	2.67	7.31	15.56	36.14	6.46**
Cu	1973	12	15	16	11		1.6	1.6	1.6	1.7		8	6	5	6	
	1974	16	10	10	11		2.3	2.5	2.4	2.7		7	6	6	6	
	1975	12	11	12	12		2.1	2.8	2.4	2.8		7	6	5	7	
	1976	13	13	13	14		2.0	2.4	2.3	2.3	0.3*	7	8	8	10	1*
	1977	9	11	13	15	2**	2.6	2.7	2.8	3.0		7	8	7	7	
Ni	1973	2.6	1.9	2.6	1.7		1.2	0.8	0.6	0.7		0.9	0.7	0.9	0.8	
	1974	<0.6	0.8	0.7	<0.6		<0.6	<0.6	<0.6	<0.6		<0.6	<0.6	0.6	0.6	
	1975	0.6	<0.6	0.8	0.8							0.6	0.6	0.6	0.7	
	1976	0.6	0.8	0.7	1.1		<0.6	0.6	0.6	1.0	0.3**	<0.6	0.7	0.7	1.1	
	1977	<0.6	0.7	0.9	0.9		1.0	1.0	1.3	1.9	0.2**	0.6	0.8	1.4	1.6	0.7*

(continued)

TABLE 33. (continued)

Constituent	Year	Sludge application rates														
		Leaf					Grain					Stover				
		0	¼-Max	½-Max	Max	LSD	0	¼-Max	½-Max	Max	LSD	0	¼-Max	½-Max	Max	LSD
		mg/kg														
Cr	1973	0.4	0.5	0.7	0.3		0.2	0.3	0.7	0.5		**0.6**	**1.5**	**2.7**	**1.0**	
	1974	1.1	1.4	0.6	1.6		0.4	0.9	0.9	0.9		1.3	1.5	1.3	1.6	
	1975	4.6	4.8	4.9	4.6		2.2	2.4	2.2	1.9		2.6	2.6	3.4	2.7	
	1976	0.2	1.0	0.8	0.9		0.8	0.8	1.7	1.3		0.7	0.5	1.0	1.0	
	1977	0.1	0.1	0.5	0.5	0.4*	0.7	0.7	0.3	0.8		1.2	2.2	2.9	2.9	
Pb	1973	3.6	2.6	2.8	3.3		2.5	1.4	2.2	2.0		2.4	1.5	1.8	3.0	
	1974	2.1	2.1	1.9	2.4		1.7	0.8	1.5	1.2		1.3	2.1	2.6	2.6	
	1975	0.7	1.5	1.0	1.3							1.5	1.5	1.7	1.6	
	1976	1.1	0.9	1.5	1.8		0.6	1.1	0.6	0.7		2.7	2.6	3.0	3.2	
	1977	2.6	3.1	2.2	2.5		<0.6	<0.6	<0.6	<0.6		**3.1**	3.3	3.4	3.1	
		%														
Ash	1973	8.36	8.43	8.02	7.38		1.73	1.30	1.40	1.39	0.26*	5.73	6.48	6.18	6.04	
	1974	7.39	6.51	6.56	7.04		2.02	1.82	1.88	1.69	0.22*					
	1975						1.90	2.11	1.71	1.78						

a/ Dry weight basis.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Most of the increased levels of Zn and Cd in corn plant tissues were due to annual applications of sludge-borne metals. But contrary to what was expected because of the higher pH in the surface, accumulative amounts of Zn and Cd in strip-mine spoil appear to affect tissue concentrations much more than in similar tissues from plots of Blount silt loam. Some of the apparent increase of Zn concentrations in plant tissues with years of applying sludge may be the result of higher annual applications of sludge-borne Zn (Table 30), but this is not true for Cd. Concentrations of Cd apparently increased throughout the years from 1973 to 1976 in response to accumulated sludge-borne Cd, but changes in tissue levels between 1976 and 1977 were not proportional to levels of Cd accumulated in the spoil materials (Table 31). Considering the last two years data, it appears that Zn and Cd concentrations are affected to a much lesser degree by accumulative sludge-borne metals than amounts applied just prior to the crop year. From the few data available, it appears that grain produced on maximum-sludge-treated spoil plots had lower ash contents during the first two years than that produced on control plots. But for other tissues and grain produced during the third year, sludge applications had little effect on ash contents.

SECTION 6

SPECIAL STUDIES

UPTAKE OF HEAVY METALS AND P BY INBRED CORN LINES AND CROSSES OF SELECTED INBREDS

General Description

Meyers (1960) suggested that plant breeders might reduce contents of radioisotopes in food by selecting or developing accumulator plants that could clear soils of particular isotopes, or by developing plants that have the capacity to produce edible plant portions with lower than normal radioisotope concentrations. The latter might be "accomplished" by developing plants which (1) absorb relatively less of the undesired elements, (2) retain in or transport the element to organs which are not normally used for food or feed, or (3) metabolize the element into a form less readily available to the consuming animal or man. Millikan (1961) indicated that differences in nutrient absorption and utilization were sometimes greater among varieties within species than between related species or genera.

This study was conducted to determine differences in the accumulations of selected elements in leaves and grain of corn inbreds when grown on control and sewage sludge-amended soil.

Twenty corn inbreds commonly used as parents for hybrids adapted to the Corn Belt were planted in Blount silt loam (Aeric ochraqualf, fine illitic, mesic) soil with and without sludge. Treatments, replications, methods of applying sludge, fertilization of control plots, etc. were described earlier in Section I where they were identified as Blount silt loam plots in the south series of lysimeter plots. At the beginning of the 1976 growing season, maximum-sludge-treated plots had received a 7-year accumulative application of 374 metric tons/ha (dry weight equivalent) of sludge solids. During the growing season, 236 mm of sludge (71 metric tons/ha of dry solids) were applied on maximum-treated plots. Appropriately lesser amounts of sludge (59 and 118 mm) were applied on other sludge-treated plots as had been the practice during previous growing seasons (Table 2).

Seeds of inbred lines were planted on ridges in 3.1 m rows of five hills each and thinned to two plants per hill. Some of the inbred lines had been previously screened for differences in Zn and Cd uptake in a greenhouse study. When about 10% of the plants of each inbred had tasseled, the ear-leaf was collected, washed in distilled water, and dried (60°C), and ground to pass a

20-mesh screen in a Wiley mill. As each inbred matured (30% grain moisture), whole ears were collected for grain, dried at 40°C, hand shelled, redried, and ground as described for leaves. Leaves and grain were analyzed for concentrations of selected elements by methods described in Section I of this report.

The preliminary F test with the least significant difference, as recommended by Carmer and Swanson (1971), was used to detect real differences in concentrations of the several elements as found in leaves and grain from different inbreds.

Discussion of Results

Uptake of Metals in Leaves of Corn Inbreds--

Although sludge application rates had not significantly increased soil contents of Fe, (Table 7) it seemed likely that the availability of this element would be higher in soil amended with sludge. However, as may be seen in Table 34, sludge applications caused higher uptake of Fe in leaves of only four inbreds. Inbred B14 was the only one to take-up significantly more Fe in leaves when grown on maximum-sludge-treated than on control plots. Inbreds Oh545, R805, and H99 produced leaves with higher Fe contents when grown on either ¼- or ½-maximum-sludge-treated plots. Within a particular treatment, inbreds showed extreme variations in capacities to accumulate Fe in leaves. The variations between inbreds were much greater than variations caused by sludge treatments. When grown on control plots leaves from inbred B14 had significantly ($P \leq 0.01$) lower Fe concentrations than those from A619 and H99, but when grown on maximum-sludge-treated plots Fe contents of leaves from B14 were intermediate to those in leaves from the other two inbreds.

Concentrations of Mn in leaves of corn inbreds are shown in Table 35. Sludge applications affected Mn concentrations in leaves of nine inbreds although total concentrations of Mn were not changed in the soil (Table 7). Except for leaves from inbred B37, sludge applications either did not significantly affect accumulation of Mn in leaves or they were associated with decreases in concentrations. When inbred W64A was grown on maximum-sludge-treated plots its leaf-Mn contents were not significantly different from leaves produced on control plots, but leaves from this same inbred grown on lesser sludge-treated plots contained significantly less Mn than those from control plots. Just as there was a trend for higher Fe contents in leaves produced on ¼- and ½-maximum-sludge-treated plots, the opposite trend for lower Mn concentrations in leaves can be seen in Table 35. Like Fe, leaf-Mn concentrations for different inbreds varied less when grown together on the ¼-maximum treated plots as compared to ranges in concentrations observed between inbreds grown on plots subjected to any other treatment.

Sludge applications drastically increased Zn concentrations in the soil surface from 68 mg/kg in control plots to 454 mg/kg in maximum-treated plots, and these increases were reflected by leaf-Zn concentrations for all inbreds. Concentrations of Zn in leaves are listed from highest to lowest in Table 36 for the 20 inbreds grown on maximum-sludge-treated plots. Without exception, leaves from inbreds grown on maximum-and ½-maximum-sludge-treated plots had significantly higher Zn concentrations than those from control plots. Inbred

TABLE 34. CONCENTRATIONS OF Fe IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

Inbred	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
A619	161.0	189.3	208.6	174.5	
B14	87.4	116.3	118.1	146.3	34.5*
Oh43	118.7	137.9	129.4	125.4	
B73	119.4	135.7	132.4	112.4	
B37	122.7	132.0	135.0	110.6	
Va26	109.3	129.8	141.4	110.2	
R806	138.7	146.2	133.8	109.4	
R802A	115.3	127.8	130.9	108.4	
R177	101.2	131.7	125.1	103.2	
H98	147.6	142.7	119.0	102.0	
Oh545	122.9	153.5	140.9	99.6	37.4**
W64A	80.1	114.5	109.1	99.2	
B77	119.6	119.5	116.2	98.1	
R805	99.3	120.6	118.3	97.2	18.6**
H99	79.2	140.0	137.8	95.4	38.8*
H100	105.9	112.0	108.1	94.5	
A632	75.5	97.6	94.7	87.0	
N28	115.1	107.5	112.1	86.3	
H96	96.9	113.6	94.0	76.9	
Mo17	94.5	103.0	83.7	68.1	

[a/] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 35. CONCENTRATIONS OF Mn IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a]

Inbred	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
H98	58.3	50.4	44.3	61.5	
Mo17	60.8	49.6	49.3	52.0	7.5*
N28	49.9	43.8	42.4	46.8	
B37	36.2	37.2	37.9	44.2	5.3*
Oh545	68.4	48.1	49.6	43.8	17.5**
W64A	52.0	35.5	34.6	43.2	12.7*
A632	35.4	32.5	27.9	40.1	7.1*
H96	49.2	36.6	34.0	37.2	
R806	39.2	31.7	29.6	37.0	
Oh43	55.3	36.5	38.6	36.6	
B14	33.5	30.3	29.8	35.2	
H100	40.5	32.8	30.0	33.7	6.3*
B73	46.8	42.7	31.8	31.6	11.0**
R805	42.3	32.4	33.4	31.5	
Va26	32.4	26.0	27.6	31.2	
A619	45.3	27.8	29.5	30.3	
R802A	29.7	23.5	26.4	29.1	
H99	41.0	27.7	23.9	27.9	10.8*
R177	39.9	26.5	23.7	26.8	9.2**
B77	27.4	28.8	24.5	25.8	

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[a] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 36. CONCENTRATIONS OF Zn IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM SOIL PLOTS.[a]

Inbred	Sludge treatment				LSD
	0	¼-Max	½-Max	Maximum	
	mg/kg				
Oh43	14.5	78.2	142.2	281.8	59.2**
R806	18.0	84.4	156.1	268.2	50.2**
H98	18.5	63.6	112.2	217.2	57.5**
A619	16.0	43.2	62.0	193.3	66.3**
Mo17	28.3	64.7	107.1	188.8	44.8**
Oh545	14.6	50.2	89.2	170.6	39.7**
B37	22.4	54.5	99.0	164.2	26.3**
R805	17.5	58.2	91.0	148.1	41.3**
Va26	17.2	51.5	77.1	144.4	31.4**
H100	20.0	40.3	65.9	140.1	43.4**
B73	19.8	48.8	77.7	133.7	32.1**
B14	17.4	48.4	71.0	130.2	33.1**
A632	16.8	37.2	52.8	113.0	6.7**
N28	17.1	32.5	56.7	109.4	23.6**
W64A	16.7	35.4	55.4	107.2	21.3**
R802A	18.8	40.8	65.3	104.9	9.9**
H99	15.2	35.6	47.9	102.9	32.2**
H96	12.9	43.3	63.5	94.3	12.8**
R177	16.0	34.3	64.8	88.0	33.6**
B77	15.4	32.0	43.7	61.8	14.3**

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[a] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

** Significantly different at $P \leq 0.01$.

Mo17 had significantly higher leaf-Zn concentrations than all other inbreds grown on control plots, but Oh43 and R806 had the highest leaf-Zn concentrations on sludge-amended soil. Leaf-Zn concentrations were not different in inbreds B77, R177, and H96 and they were always members of group exhibiting the lowest leaf-Zn concentrations, regardless of treatment.

At the beginning of the 1976 growing season, annual sludge applications had increased soil Cd contents (0-15 cm depth) from 0.3 to 21 mg/kg on maximum-treated plots. Inbreds grown on maximum-sludge-treated plots are ranked from highest to lowest according to leaf-Cd concentrations in Table 37. Leaves from all inbreds grown on maximum-sludge-treated plots had significantly higher concentrations of Cd as compared to concentrations in leaves from control plots. Concentrations of Cd were below detectable limits of 0.06 mg/kg in leaves of inbreds B73 and R805 grown on control plots. Leaves from all except four inbreds grown on ½-maximum-sludge-treated plots contained higher concentrations of Cd than leaves from the same inbreds grown on control plots. Regardless of soil treatment, leaves from inbred H98 always contained significantly higher concentrations of Cd than leaves from any other inbred except B37. Inbreds R805, Va26, B73, H96, H99, and R117 constituted a group whose members had about the same leaf-Cd concentrations that were lower than those in leaves from other inbreds grown under comparable conditions.

Total concentrations of Cu were increased from 20 to 136 mg/kg in the surface of maximum-sludge-treated soil. As seen in Table 38, higher Cu levels in soil were reflected by higher levels in the leaves of most inbreds. Regardless of treatment, R117 contained higher levels and H96 lower levels of Cu in leaves than other inbreds. Inbreds B77 and H99 showed the least change in leaf-Cu concentrations as levels of Cu in soil were increased by sludge loading rates. On control plots, these two inbreds accumulated relatively high levels of Cu in leaves.

Concentrations of Ni in the soil surface were increased from 27 to 52 mg/kg in maximum-sludge-treated plots. There was a trend toward increased Ni concentrations, with higher sludge loading rates, in the leaves of several inbreds (Table 39). While only leaves from inbreds Oh43 and Oh545 had significantly higher levels of Ni as a result of higher concentrations in the soil, seven of the inbreds including Oh545 had the highest Ni concentrations in leaves from the one-half-maximum-sludge-amended plots.

Concentrations of Cr in soil were increased from 48 to 275 mg/kg by maximum sludge loading rates. Of all the heavy metals, only Zn concentrations were increased to a greater extent in the soil. However, unlike Zn concentrations, elevated sludge-borne Cr concentrations in soil were seldom accompanied by increased concentrations of the metal in corn leaves. Significant increases in Cr levels in leaves from plots with one-fourth- and/or one-half-maximum sludge treatments occurred in the inbreds Oh545, A619, H98, H99, and B73. However, Oh545 is the only one in which the increase in Cr in leaves from the maximum-sludge-treated plots was also significant. Levels of Cr in leaves from the one-half-maximum plots always equaled or exceeded those from maximum-sludge-treated plots.

TABLE 37. CONCENTRATIONS OF Cd IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a]

Inbred	Sludge treatment				LSD
	0	¼-Max	½-Max	Maximum	
	mg/kg				
B37	0.92	12.01	36.91	62.93	15.69**
H98	1.49	11.47	26.02	48.84	19.21**
Mo17	0.59	5.32	14.85	27.06	6.99**
N28	0.39	5.77	10.11	23.41	5.64**
B14	0.32	2.09	5.01	19.75	5.53**
H100	0.25	1.48	3.76	15.40	5.61**
B77	0.34	4.61	6.54	14.67	3.83**
A632	0.14	0.76	2.26	11.45	3.35**
R806	0.40	3.82	6.52	11.38	3.96**
Oh43	0.38	1.83	4.71	11.33	3.28**
R802A	0.16	1.11	3.98	10.74	1.06**
W64A	0.15	0.82	2.74	9.79	2.57**
Oh545	0.22	1.46	4.16	9.57	1.97**
A619	0.41	1.49	3.02	8.06	2.10**
H99	0.24	0.82	1.58	6.81	2.66**
H96	0.22	1.01	1.90	5.03	1.70**
R177	0.18	0.63	2.05	5.00	2.15**
B73	<0.06	0.29	0.96	3.74	3.26*
Va26	0.16	0.57	1.39	3.71	0.94**
R805	<0.06	0.30	0.92	2.47	1.13**

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[a] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

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TABLE 38. CONCENTRATIONS OF Cu IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a]

Inbred	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
R177	17.4	18.8	21.1	21.6	2.4*
Mo17	9.0	12.4	14.5	17.8	2.3**
H98	10.9	13.6	12.9	17.8	3.2*
B14	9.2	12.3	12.5	17.7	5.7**
R806	11.1	15.2	16.7	17.6	3.2*
H100	12.8	12.4	13.2	17.3	3.6**
Oh43	9.5	12.9	13.9	17.0	3.8*
R802A	12.5	14.2	16.5	16.2	
W64A	10.5	13.1	12.6	15.9	3.5**
N28	12.5	14.0	14.3	15.1	
H99	13.9	14.6	15.3	15.0	
B37	10.4	12.2	13.6	14.8	2.6*
B73	12.6	16.4	16.3	14.7	2.3**
Oh545	9.2	12.1	12.4	14.4	2.1**
A619	10.8	13.8	14.8	13.3	
Va26	10.0	13.0	13.3	12.5	
A632	9.2	11.3	10.9	12.4	
B77	10.4	13.0	12.5	11.2	
R805	7.7	9.9	9.9	10.6	
H96	5.8	8.3	9.5	9.2	1.2**

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[a] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 39. CONCENTRATIONS OF Ni IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

Inbred	Sludge application rates				LSD
	0	¼-Max	½-Max	Maximum	
	mg/kg				
A619	1.3	1.7	1.8	2.5	
H98	0.3	0.9	0.8	1.3	
R802A	0.9	0.9	1.0	1.1	
B37	0.6	0.9	1.0	1.2	
B73	0.5	0.5	0.7	1.2	
Oh43	0.7	0.7	0.8	1.1	0.3*
B14	0.9	0.8	0.7	1.0	
R177	0.5	0.9	1.5	1.0	
W64A	1.0	0.4	0.6	0.9	
H99	0.6	0.7	1.1	0.9	
Mo17	0.5	0.4	1.4	0.8	
H96	0.5	0.7	0.5	0.8	
N28	0.6	0.7	0.8	0.7	
R806	0.3	1.0	0.7	0.7	
Oh545	0.3	0.7	0.8	0.6	
B77	0.4	0.3	0.4	0.5	
R805	0.5	0.6	0.6	0.5	
A632	0.3	0.4	0.5	0.5	
H100	0.3	0.5	0.6	0.4	
Va26	0.2	0.2	0.2	0.3	

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a/ Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

* Significantly different at $P \leq 0.05$.

TABLE 40. CONCENTRATIONS OF Cr IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

Inbred no.	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
Oh545	1.1	2.5	2.9	2.4	0.9*
A619	0.6	3.3	4.3	2.4	2.4*
N28	1.4	1.7	4.0	2.1	
H98	1.6	3.6	2.6	1.9	1.2*
H96	1.3	1.6	1.9	1.9	
B37	1.0	2.6	4.6	1.8	
H100	1.3	1.7	2.0	1.7	
B14	0.7	1.2	3.1	1.7	
Oh43	1.2	2.5	3.0	1.6	
H99	0.9	2.8	3.4	1.6	1.4**
Va26	0.9	1.2	3.2	1.6	
R177	0.9	2.6	3.9	1.4	
B77	0.9	1.1	1.6	1.4	
B73	0.5	1.6	4.3	1.4	2.6*
R805	0.9	2.3	2.9	1.3	
W64A	1.0	2.0	1.9	1.2	
R802A	0.5	1.3	2.5	1.1	
Mo17	0.7	1.2	2.7	0.9	
A632	0.4	1.4	0.8	0.8	
R806	0.3	2.0	2.2	0.7	

[a/] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Lead concentrations were increased in the soil surface from 28 to 120 mg/kg by maximum sludge loading rates. But these increases affected concentrations of Pb in corn leaves very little. The data in Table 41 show that Pb uptake was significantly increased in the leaves from the inbreds B73, A632 and B77 by sludge applications at intermediate loading rates. The inbred B73 tended to take-up more Pb than other inbreds, regardless of treatment.

Concentrations of Selected Elements in Grain From Corn Inbreds--

Concentrations of P in grain from corn inbreds are shown in Table 42. Only four inbreds showed significant differences in P in grain in response to exceedingly high loading rates of sludge-borne P. However, treatment differences were not expected to be large since control plots were treated with superphosphate which supplied 134 kg P/ha each year for eight years including the crop year. Regardless of treatment, significant differences were found in capacities of inbreds to accumulate P in grain. Grain from B14 and H100 contained more than double the concentration of P in grain from inbreds Oh43 and Oh545.

Concentrations of Mn in grain are shown in Table 43. In grain from all except two inbreds, sludge applications caused significant reductions of Mn concentrations. Even in the two inbreds that did not show a significant response, grain-Mn concentrations tended to be lower with higher sludge application rates. Inbreds exhibited considerable differences in capacities to accumulate Mn in grain and these differences between inbreds were just as large when they were grown on control as compared to sludge-treated plots. But inbreds which accumulated higher amounts of Mn in grain when grown on control plots did not always contain higher concentrations when grown on sludge-treated soil. The reason for lower Mn concentrations in grain produced on sludge-amended soil is not known. Based on what is known about soil-Mn, this finding is contrary to expectations. Relative to amounts present in soil very little sludge-borne Mn was supplied, but it was hypothesized that sludge applications would increase Mn availability.

Inbreds in Table 44 are listed by highest to lowest concentrations of Zn in grain from plants grown in maximum-sludge-treated plots. Considering Zn concentrations in grain from all 20 inbreds, only grain from H99 did not contain significantly enhanced levels as a result of accumulated amounts of sludge-borne Zn in the soil. Concentrations of Zn in grain from all inbreds except H100 and H99 were significantly increased by ½-maximum sludge treatments. One-fourth maximum sludge treatments caused increased Zn concentrations in grain from nine inbreds. Concentrations of Zn were significantly higher in grain from inbred R117 than in other inbreds grown on control plots, but B37 and A619 had higher levels than other inbreds grown on maximum-sludge-treated soil. Inbreds B14, Mo17, W64A, and Va26 were among groups that accumulated the lowest concentrations of Zn in grain, but were not different from each other at any treatment level.

In Table 45, inbreds are listed in order of high to low accumulators of Cd in grain from maximum-sludge-treated plots. Concentrations of Cd in grain from all inbreds grown on maximum-sludge-treated plots, except H99, Oh545, and R805, were significantly higher than those in grain from plants grown on

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TABLE 41. CONCENTRATIONS OF Pb IN LEAVES OF CORN FROM INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.a/

Inbred	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
B73	5.0	6.0	7.2	5.3	1.3**
B14	4.0	4.4	4.2	5.3	
A619	3.6	4.8	5.3	4.6	
B37	3.3	4.0	4.1	4.6	
N28	4.2	4.3	5.5	4.3	
H96	3.6	4.5	4.1	4.3	
H98	3.2	4.6	3.9	4.0	
R805	3.7	4.2	3.9	3.6	
H100	3.1	3.5	3.9	3.5	
Oh43	3.9	2.5	2.9	3.3	
R177	4.4	3.7	5.0	3.2	
A632	3.5	4.2	3.3	3.0	0.7*
R802A	2.8	4.4	4.5	3.0	
W64A	2.6	3.7	2.6	2.9	
B77	2.5	2.9	4.1	2.9	0.8*
Va26	2.4	2.5	3.9	2.7	
R806	2.8	3.5	3.7	2.5	
Oh545	2.2	2.5	3.3	2.5	
H99	1.7	2.0	2.4	2.4	
Mo17	3.4	3.2	3.1	1.6	

a/ Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 42. CONCENTRATIONS OF P IN GRAIN FROM CORN INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a]

Inbred	Sludge application rates 0	¼-Max	½-Max	Maximum	LSD
	---------------------------mg/kg---------------------------				
B14	5132	5201	4812	4909	n.s.
H100	4075	4092	4079	4641	n.s.
A632	3832	3326	4299	4467	n.s.
R177	4670	4598	4195	4301	n.s.
R802A	4120	3579	3594	3877	n.s.
N28	3745	3668	3799	3823	n.s.
H98	2760	3028	3363	3797	648**
B77	3373	3024	3331	3748	471*
H96	3482	2937	3079	3536	440**
B37	3234	3142	3794	3458	n.s.
H99	3866	3459	3292	3444	n.s.
A619	2906	2878	2827	3278	n.s.
R806	2851	3044	3100	3184	n.s.
Mo17	2918	2330	3089	3143	497**
W64A	3077	2784	3022	3039	n.s.
Va26	2860	2517	2618	3026	n.s.
R805	2885	2996	2621	2818	n.s.
B73	2620	2558	2395	2551	n.s.
Oh43	1975	1739	1945	2217	n.s.
Oh545	1681	1731	2336	2071	n.s.

[a] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 43. CONCENTRATIONS OF Mn IN GRAIN FROM CORN INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

	Sludge application rates				
Inbred	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
Oh43	7.4	6.0	5.8	5.3	1.1**
H96	6.6	5.8	5.5	5.2	
R177	8.6	7.3	6.2	5.2	1.8**
R805	6.1	5.7	4.8	4.8	1.0*
H100	7.2	5.3	4.5	4.6	
R802A	9.1	6.9	6.1	4.1	2.0**
W64A	6.7	5.4	4.7	4.0	1.4*
A619	6.6	5.2	4.5	3.9	1.0**
Oh545	4.4	3.5	4.1	3.8	0.5*
H98	4.9	3.7	3.6	3.5	1.0**
Va26	4.9	4.1	3.8	3.5	1.0**
B73	5.4	4.4	3.7	3.3	1.2**
H99	5.1	4.1	3.5	3.2	1.1**
R806	4.3	2.7	3.4	3.2	0.9*
A632	6.3	5.0	3.8	3.1	2.2**
B37	8.9	5.4	3.8	3.1	2.9**
B14	6.6	4.7	4.4	2.9	1.5**
Mo17	4.7	2.9	2.1	2.1	0.9**
B77	3.7	2.7	2.1	2.1	0.7**
N28	4.6	2.6	2.4	1.8	0.6**

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a/ Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 44. CONCENTRATIONS OF Zn IN GRAIN FROM CORN INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.a/

Inbred	Sludge application rates				LSD
	0	¼-Max	½-Max	Maximum	
	---mg/kg---				
A619	30.2	40.6	46.6	70.0	16.1**
B37	27.2	34.8	50.8	64.3	14.4**
H98	27.8	34.2	40.8	54.5	9.8**
H96	26.9	38.3	42.2	54.0	12.2**
Oh43	21.4	34.4	44.4	52.4	8.7**
R177	35.8	42.3	44.3	52.4	11.2**
Oh545	28.5	33.0	43.8	51.6	14.1**
R806	28.6	37.0	42.5	50.4	8.8**
N28	26.5	31.6	38.8	47.0	6.7**
H100	25.5	30.4	33.2	46.9	12.2**
A632	20.9	26.7	35.4	46.3	9.0**
B77	19.2	32.4	33.6	44.6	9.7**
R805	24.0	33.7	41.4	43.7	8.4**
B73	25.5	30.8	34.8	43.1	6.2**
Va26	23.6	28.9	33.9	40.3	7.5**
R802A	25.2	26.1	31.0	40.0	6.4**
W64A	21.1	28.9	36.3	38.7	5.3**
Mo17	23.4	28.2	35.2	37.7	3.4**
B14	22.3	29.5	32.4	34.3	6.7*
H99	26.1	27.4	30.8	33.8	n.s.

a/ Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s. Not significantly different.

TABLE 45. CONCENTRATIONS OF Cd IN GRAIN FROM CORN INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

Inbred	Sludge application rates 0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
B37	0.12	0.66	2.33	3.87	1.76**
H98	0.11	0.44	0.82	2.43	0.81**
Mo17	0.08	0.34	0.30	1.20	0.24**
B77	0.16	0.47	0.57	1.06	0.27**
B14	0.11	0.13	0.27	0.73	0.27**
H100	<0.06	<0.06	0.08	0.51	0.23**
R806	0.07	0.36	0.23	0.40	0.18**
N28	0.08	0.14	0.15	0.38	0.20**
A632	0.11	0.15	0.21	0.37	0.14**
R802A	<0.06	0.07	0.11	0.34	0.12**
R177	0.16	0.17	0.10	0.33	0.14**
W64A	0.06	0.10	0.15	0.31	0.06**
A619	0.10	0.12	0.16	0.28	0.09**
H99	0.11	0.12	0.13	0.23	n.s.
Oh43	0.09	0.08	0.13	0.19	0.80*
H96	0.07	<0.06	<0.06	0.18	0.11*
Va26	0.09	0.09	0.11	0.18	0.06**
Oh545	0.12	0.12	0.12	0.16	n.s.
B73	0.09	0.07	0.11	0.15	0.05*
R805	0.06	0.09	0.08	0.08	n.s.

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a/ Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s. Not significantly different.

control plots. Only 8 and 4 inbreds, respectively, had significantly higher grain-Cd concentrations when grown on ½- and ¼-maximum-sludge-treated plots. On maximum-sludge-treated plots both H98 and B37 had significantly higher grain-Cd concentrations than all other inbreds. Across all treatments, inbreds H96, H100, Oh43, R802A, R805, and W64A were always members of the group of low accumulators of Cd in grain.

These data suggest that the uptake of Cd was under rather simple genetic control. For example, 93% of the genetic endowment of A632 was derived from B14; 75% of R802A was from B37. Inbreds A632 and B14 grown on maximum-sludge-treated plots had 0.37- and 0.73-mg Cd/kg, respectively, in grain. Under the same conditions, R802A and B37, respectively, had 0.34- and 3.87-mg Cd/kg in grain. These were significant differences ($P \leq 0.01$) between closely related inbreds. Furthermore, the coefficients of relationship of Oh43 to the three inbreds A619, Va26, and H98 are 0.75, 0.50, and 0.50, respectively. Inbred H98 was one of the high Cd-accumulators, Va26 and Oh43 were among the low accumulators, and A619 was among those considered as intermediate Cd-accumulators.

Only inbred lines B37 and H98 exhibited the capacity to accumulate high amounts of both Zn and Cd. Inbred lines Oh43 and Oh545 accumulated high amounts of Zn and low amounts of Cd, Va26 and H99 contained low concentrations of both Zn and Cd, and B14 had low Zn and high Cd concentrations. The capacity to accumulate Zn and Cd varied to such an extent among inbreds that mechanisms for absorption and/or translocation of the two metals appear to be separate.

Concentrations of Cu in grain from inbreds are presented in Table 46. Only 4 inbreds had higher Cu concentrations in grain as a result of sludge applications. Between inbreds, grain-Cu concentrations varied considerably, regardless of treatment. To a large extent, inbreds that produced grain with the higher Cu levels on control soils also had higher grain-Cu contents when grown on sludge-amended soil. For all treatments inbreds R117, Mo17, and R802A produced grain with significantly higher ($P \leq 0.01$) levels of Cu than was contained in grain from inbreds H96, R805, and N28.

These results suggest that variations in concentration levels of P and metals in corn leaves and grain are determined as much by heritable differences as by differences in concentrations available in soils for plant uptake.

Inheritance of the Capacity to Accumulate Cd--

Making use of available materials, 6 inbreds selected from the screening study and their F_1, F_2, and back-cross progeny were planted in 1977 on the same plots where the screening study had been conducted. Inbreds B37 and H98 were selected as high accumulators of Cd and inbreds R805 and B73 as low accumulators of Cd. Unfortunately, all of the progeny needed to assess the relative importance of heredity and environment by generation mean analysis as outlined by Mather and Jinks (Biometrical Genetics, Cornell University Press, 1971) were not available. Thus, inbreds Va26 and R802A having low to intermediate and intermediate capacities, respectively, to accumulate Cd and some of their crosses with the above inbreds were included in the preliminary study.

TABLE 46. CONCENTRATIONS OF Cu IN GRAIN FROM CORN INBREDS GROWN ON CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a/]

Inbred	Sludge application rates				LSD
	0	¼-Max	½-Max	Maximum	
	---mg/kg---				
R177	3.2	4.0	5.1	4.9	1.4*
Mo17	2.3	2.8	2.9	3.1	0.4*
R802A	2.6	2.6	2.7	2.9	
A632	3.0	2.8	2.6	2.7	
B37	1.7	2.1	2.6		
A619	1.9	2.7	2.4	2.6	
W64A	4.2	2.4	2.6	2.6	
H99	1.6	2.0	2.2	2.5	0.5*
R806	1.8	2.0	2.1	2.2	
B73	1.5	1.8	1.7	2.0	
B77	1.6	2.3	2.1	1.8	
Oh43	1.6	1.6	1.9	1.7	
H98	1.2	1.4	1.3	1.7	
H100	1.4	1.4	1.6	1.6	
Va26	1.3	1.6	1.7	1.5	
B14	1.5	1.5	1.6	1.2	
Oh545	1.3	1.2	1.4	1.2	
H96	0.8	1.0	0.9	1.1	
R805	0.9	1.2	1.5	1.1	0.3*
N28	0.8	1.0	0.9	1.0	

[a/] Concentrations are ranked from highest to lowest uptake by inbreds grown on maximum-sludge-treated plots.

* Significantly different at $P \leq 0.05$.

Concentrations of Cd in leaves and grain of inbred lines and their progeny are shown in Table 47 and 48, respectively. It is noteworthy that in 1976 inbreds B37, H98, R802A, B73, Va26, and R805 grown on maximum-sludge-treated plots had leaf-Cd concentrations of 62.9, 48.8, 10.7, 3.7, 3.7, and 2.5 mg/kg (Table 37) respectively, whereas in 1977 the respective inbreds had concentrations of 95.3, 87.0, 16.2, 4.4, 5.6, and 3.2 mg/kg. Concentrations of Cd in leaves were somewhat higher in 1977, but differences between inbreds were about the same. In 1977, inbred B37 did not produce grain on maximum-sludge-treated plots, but all other comparisons of grain-Cd concentrations showed that levels were not significantly different than those found in grain produced the year before by each of the inbreds. Thus, this study established the consistency of differences in capacities of inbreds to accumulate Cd. The progeny of crosses made with high (B37) by intermediate (R802A) capacities to accumulate Cd had higher levels than the progeny of low (R805) by low (B73) crosses. The seed planted for the B37 x H98 cross may have been mislabeled, because Cd concentrations in both leaves and grain were too low. Progeny of the low (R805) by low (B73) inbreds had expected leaf- and grain-Cd concentrations. But back-crosses of high (B37) and low (B73) to the F_1 generation of these two inbreds did not yield expected results. Probably the plots size was too small and this study will be repeated on larger plots with adequate representation of all appropriate generations as soon as they can be produced.

CONCENTRATIONS OF SELECTED INORGANIC ELEMENTS IN FRACTIONS OF CORN AND WHEAT KERNELS

General Description

With regard to essential and nonessential elements, dry milling processes result in concentration reductions in fractions used to prepare food for human consumption and increases in fractions used to supplement animal rations. To our knowledge, no one has compared concentrations in whole kernels to those in kernel fractions obtained from a single batch of grain. Furthermore, no information was found in the literature regarding concentration changes in individual parts of the kernel as the concentration of a particular element is changed in whole kernels. That is, it had not been determined whether or not trace element concentrations in the endosperm fraction are enhanced in proportion to increased amounts in the whole kernel. The objective of this study was to obtain information needed to estimate increased amounts of Pb, Zn, Cu, Ni, and Cd in human diets containing cereal grain food products made from corn (*Zea mays* L.) and wheat (*Triticum aestivium* L.) grains which contain enhanced concentrations of several elements. Concentrations of the essential elements Fe, Mn, Cr, Ca, Mg, and P were also determined in whole and fractions of grain, because dietary concentrations of these elements are important in ameliorating effects of inorganic elements in animal diets.

Three corn single-crosses, selected on the basis of known capacities of parent lines to accumulate Cd in grain, were grown in a field which had been reclained from strip-mined spoil. The spoil material had been amended with

TABLE 47. CONCENTRATIONS OF Cd IN LEAVES OF SELECTED CORN INBREDS AND PROGENY.

Inbred or progeny	Sludge application rates				
	0	¼-Max	½-Max	Maximum	LSD
	mg/kg				
B37	1.07	18.23	48.20	95.34	18.97**
H98	1.85	22.97	45.02	87.04	17.23**
R802A	0.23	1.94	4.94	16.25	2.54**
B37 x H98	0.23	2.52	5.35	21.14	4.09**
B37 x R802A	0.30	1.15	15.45	35.01	20.88*
R802A x B37	0.10	1.36	19.19	28.16	17.90*
R802A(R802A x B37)	0.25	3.59	13.41	24.82	9.45**
B37(R802A x B37)	0.26	1.75	5.40	18.08	6.19**
(R802A x B37)F_2	0.43	6.03	17.16	26.59	17.61*
R805	0.14	0.67	1.05	3.21	1.51**
B73	0.08	0.33	1.17	4.38	1.20**
Va26	<0.06	0.79	1.34	5.56	1.03**
Va26 x R805	0.35	1.93	3.56	9.02	4.98*
R805 x B73	0.22	0.63	2.42	5.87	0.86**
R805(R805 x B73)	0.28	0.58	1.62	4.86	2.69**
B73(R805 x B73)	0.11	0.71	2.21	4.49	1.48**
(R805 x B73)F_2	0.22	0.80	2.12	7.33	1.76**
B37(B37 x B73)	0.27	1.44	2.57	10.88	4.36**
B73(B37 x B73)	0.29	1.54	3.07	8.85	3.15**
(B37 x B73)F_2	0.23	0.97	1.61	6.91	1.11**

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 48. CONCENTRATIONS OF Cd IN GRAIN FROM SELECTED INBRED LINES OF CORN AND THEIR PROGENY.

Inbred or progeny	Sludge application rates				LSD
	0	¼-Max	½-Max	Maximum	
	mg/kg				
B37	0.11	0.73	1.97		0.84**
H98	0.13	0.65	1.19	1.70	1.03**
R802A	<0.06	<0.06	0.17	0.38	0.10**
B37 x H98	<0.06	0.07	0.13	0.25	0.08**
B37 x R802A	<0.06	0.10	0.41	0.79	0.60**
R802A x B37	<0.06	<0.06	0.46	0.61	0.45**
R802A(R802A x B37)	<0.06	0.10	0.33	0.67	0.07**
B37(R802A x B37)	<0.06	0.07	0.24	0.47	0.22**
R802A x B37 F_2	<0.06	0.17	0.23	0.44	0.20*
R805	<0.06	<0.06	<0.06	< 0.06	
B73	<0.06	<0.06	0.08	0.12	0.07**
Va26	<0.06	<0.06	0.07	0.21	0.09**
Va26 x R805	<0.06	0.10	0.14	0.16	0.06**
R805 x B73	<0.06	<0.06	0.07	0.10	0.06**
R805(R805 x B73)	<0.06	<0.06	<0.06	< 0.06	
B73(R805 x B73)	<0.06	<0.06	0.10	0.13	0.07*
R805 x B73 F_2	<0.06	<0.06	0.07	0.14	0.08**
B37(B37 x B73)	<0.06	<0.06	0.07	0.20	0.10*
B73(B37 x B73)	<0.06	<0.06	0.07	0.17	0.09*
B37 x B73 F_2	<0.06	<0.06	<0.06	0.11	

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

262 mt/ha (dry weight equivalent) of anaerobically digested sewage sludge, applied over a period of 5 years. Samples of grain from two other single-crosses were obtained from corn breeding studies located on a conventionally fertilized prairie soil at the University of Illinois South Farm.

Subsamples of the above corn grain (100g) were soaked 36-48 hours in deionized water. The germ was then separted from corn kernels by hand. Whole kernel corn, separated corn germ, and the degermed kernel were dried at 60°C and ground in a Wiley mill to pass a 20-mesh screen. Individual corn germ (12-13g) samples were wrapped in filter paper before placing them in the extraction thimble of a sohxlet apparatus. Hexane was used as the solvent for extracting oil from the corn germ material. The solvent was removed from the oil under reduced pressure and the defatted corn germ-cake was dried to constant weight in an oven (60°C).

Other samples (4kg) of corn grain from each of the three single-crosses discussed above and another hybrid grown at two locations on reclaimed strip-mined spoil banks amended with sludge were separated into endosperm, bran, germ, and feed fractions, by the use of laboratory dry-milling equipment.

Winter wheat was drilled in October 1976 into the surface of Blount silt loam (Aeric ochraqualf, fine, illitic, mesic) plots that had previously been planted to soybeans each year. Plots had been irrigated with digested sewage sludge for eight consecutive years. When sludge applications were terminated and wheat was planted, one set of replicated plots had received the equivalent of 410 mt/ha and another set had received 205 mt/ha of dry sludge solids. The sludge was applied in previous years as a 3 to 4% solids in suspension by furrow irrigation while soybeans were growing on ridges. When the wheat grain was harvested for determination of yields, subsamples (700g) were collected and separated into flour, shorts, and bran fractions by the use of a laboratory (Buhler) mill.

Except for corn oil, samples of all corn and wheat grain fractions were digested with a nitric-perchloric acid combination preparatory to analyzing them for concentrations of Ca, Mg, P, Cd, Zn, Cu, Ni, Mn, Cr, Fe, and Pb. Flame atomic absorption spectrophotometry (Hinesly et. al., 1977) was employed for metal analyses and P concentrations were determined colorimetrically with the use of the vanadomolybdate finish. Corn oil samples (2g) were first ashed by using concentrated nitric acid, as described by Garcia et. al. (1974), after which they were analyzed for contents of heavy metals by methods used for other grain fractions.

Discussion of Results

Concentrations of Selected Elements in Whole and Degermed Kernels, Defatted Germ, and Germ Oil of Corn--

Concentrations of eight metals in corn grain and the various hand-separated fractions of kernels are presented in Table 49. Metal concentrations in grain from the two hybrids grown on normal, uncontaminated soil are within the range of expected levels. In comparison with these normal levels, corn grain from the three single-crosses grown on reclaimed strip-mined lands had high concentrations of Cd, Zn, and Fe. Of the three single-crosses grown on sludge-amended spoil banks, only grain from R802A x R806 had a higher

TABLE 49. CONCENTRATIONS OF METALS IN WHOLE AND HAND-SEPARATED FRACTIONS OF CORN KERNELS FROM SINGLE-CROSSES (1) B73 x Mo17 AND (2) C103 x B37 GROWN ON NORMAL SOIL AND (3) B73 x Oh545, (4) R802A x R806, AND (5) FRMo17 x FR14A GROWN ON STRIP-MINED SPOIL AMENDED WITH SEWAGE SLUDGE.

Single-cross	Metals							
	Cd	Zn	Cu	Ni	Pb	Cr	Fe	Mn
	----------mg/kg (dry weight)----------							
	Whole kernels							
(1)	<0.08	14.1 ± 1.0	1.5 ± 0.1	1.8 ± 0.3	1.0 ± 0.2	<0.4	17.1 ± 2.1	2.9 ± 0.2
(2)	<0.08	16.6 ± 1.1	1.9 ± 0.3	1.4 ± 0.1	2.0 ± 0.4	1.1 ± 0.3	16.3 ± 1.9	5.3 ± 0.5
(3)	0.30 ± 0.04	47.1 ± 6.9	1.8 ± 0.2	1.6 ± 0.2	1.3 ± 0.1	0.5 ± 0.2	30.2 ± 1.0	4.8 ± 0.6
(4)	0.65 ± 0.05	41.2 ± 4.6	3.3 ± 0.3	1.8 ± 0.1	1.0 ± 0.1	0.6 ± 0.2	27.8 ± 1.5	5.8 ± 0.6
(5)	0.93 ± 0.14	27.3 ± 2.6	1.8 ± 0.2	1.7 ± 0.2	1.6 ± 0.1	0.8 ± 0.4	21.0 ± 3.1	4.9 ± 0.3
	Degermed kernels							
(1)	<0.08	3.5 ± 0.1	1.0 ± 0.3	1.3 ± 0.1	1.1 ± 0.2	<0.4	7.8 ± 1.2	1.0 ± 0.1
(2)	<0.08	4.5 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.6 ± 0.4	1.0 ± 0.2	6.7 ± 0.4	2.3 ± 0.3
(3)	0.29 ± 0.07	11.4 ± 1.1	1.3 ± 0.2	0.8 ± 0.1	1.1 ± 0.1	0.6 ± 0.1	7.3 ± 1.0	2.1 ± 0.2
(4)	0.62 ± 0.08	12.2 ± 0.5	2.2 ± 0.1	1.0 ± 0.2	1.6 ± 0.5	0.5 ± 0.1	9.9 ± 1.6	3.1 ± 0.1
(5)	0.78 ± 0.02	9.9 ± 1.0	1.6 ± 0.2	1.2 ± 0.5	1.7 ± 0.4	0.9 ± 0.4	8.9 ± 1.2	2.3 ± 0.2
	Defatted germ							
(1)	0.50 ± 0.01	172.4 ± 2.0	10.7 ± 0.1	1.6 ± 0.1	5.4 ± 0.8	0.9 ± 0.1	113.2 ± 0.9	17.4 ± 0.3
(2)	0.75 ± 0.05	204.3 ± 1.1	11.5 ± 0.3	1.5 ± 0.3	8.4 ± 1.2	0.8 ± 0.2	118.6 ± 0.2	29.8 ± 0.5
(3)	1.55 ± 0.07	449.5 ± 6.8	8.7 ± 0.4	7.9 ± 0.3	5.5 ± 0.4	1.1 ± 0.1	190.3 ± 5.2	22.5 ± 1.1
(4)	2.44 ± 0.07	369.2 ± 4.2	18.4 ± 0.4	8.4 ± 1.1	3.5 ± 0.4	1.2 ± 0.3	226.5 ± 5.4	28.1 ± 0.2
(5)	4.42 ± 0.05	265.3 ± 4.2	11.9 ± 0.5	5.9 ± 0.4	2.1 ± 0.4	1.5 ± 0.2	158.1 ± 4.4	25.3 ± 0.2
	Oil							
(1)	<0.05	0.62	0.28	<0.25	<0.25	0.8	0.63	0.19
(2)	<0.05	1.31	<0.15	<0.25	0.34	1.6	0.22	0.35
(3)	<0.05	0.44	0.34	0.68	<0.25	<0.05	<0.10	<0.15
(4)	<0.05	0.28	<0.15	<0.25	<0.25	<0.05	<0.10	<0.15
(5)	<0.05	1.08	<0.15	0.44	0.29	<0.05	<0.10	<0.15

concentration of Cu than was found in grain from other sources. As expected from results reported by others (Garcia et. al., 1974), metal concentrations were highest in defatted germ materials and lowest in the oil extracted from the germ. Except for Pb and Cr, concentrations of metals were lower in the degermed kernel fraction than in whole grain. Removing the germ did not change concentrations of Pb and Cr in the remaining material as compared to those found in whole grain. Concentrations of Zn, Fe, and Mn were markedly reduced in the degermed fraction as compared to concentrations in whole kernels. The degermed fraction of corn kernels constituted 86 to 89% of the dry weight of whole grain, while the proportion of defatted germ ranged from 6.3 to 7.9% and oil from 3.4 to 6.7%. The highest oil content was in the germ of grain produced by the single-cross R802A x R806, which was expected because of the hybrid's breeding for this attribute. Even though the defatted germ was a small component of the whole kernel, it contained about 85 and 70% of the total Zn and Cd, respectively, in grain from plants grown on normal soils. Where whole grain concentrations of Zn and Cd were enhanced over those of normal grain as a result of differences in growing conditions and genetic selection, only about 65 and 30%, respectively, of the total grain-Zn and -Cd were contained in the defatted germ fraction.

Concentrations of Ni in whole knernels of corn grain varied very little, regardless of source. But the defatted germ of grain produced on strip-mined spoil contained about 30% of the total grain-Ni as compared to only 6 to 7% in the same fraction of kernels produced on normal soils. About 50, 40, and 35%, respectively, of the total Fe, Cu, and Mn contained in whole grain resided in the defatted germ fraction.

Concentrations of Selected Elements in Corn Grain Fractions Separated by Dry Milling--

Further information about the distribution of metal concentrations in grain was obtained from the fractions separated by a dry milling operation (Table 50). All of the grain fractionated by dry milling was produced on sewage sludge-amended, strip-mine spoil banks. Grain from each of the three single-crosses grown on strip-mined land and used first to obtain the results presented in Table 49 was included in the dry milling fractionation study. To complete the five sources, grain from a hybrid (Ainsworth X-516) grown at two different locations on strip-mined spoil amended with sludge was also included in the dry milling study. The endosperm fractions obtained by dry milling amounted to 72 to 74% of the dry weight of whole corn grain. This fraction contained flour, meal, and grits which are usually separated during the milling operation. The feed fraction, containing light materials from the second germ-aspirator and tail-sifter, made up from 14.5 to 15.8% of the total dry weight of grain. Amounts of bran ranged from 3.8 to 4.4% of total grain weight and consisted of light materials from the first three break- and the first germ-aspirators. The germ fraction contained the heavy materials from the first germ-aspirator and amounts ranged from 7.2 to 7.9% of total grain weights.

Results presented in Table 50 show that about 49% of total amounts of Zn and Cd in whole grain was retained in the endosperm fractions. The endosperm contained on the average 39, 44, 55, and 57%, respectively, of whole kernel amounts of Cu, Ni, Fe, and Mn. Results compiled in Table 51 show that the

TABLE 50. CONCENTRATIONS OF SELECTED METALS IN WHOLE AND FRACTIONS OF CORN KERNELS SEPARATED BY DRY-MILLING PROCESSES.a/

Grain source	Metals							
	Cd	Zn	Cu	Ni	Pb	Cr	Fe	Mn
	mg/kg (dry weight)							
	Whole kernels							
(1)	0.38 ± 0.04	40.5 ± 2.7	1.7 ± 0.1	1.6 ± 0.1	0.21 ± 0.02	0.38 ± 0.09	32.6 ± 2.4	4.7 ± 0.2
(2)	0.58 ± 0.01	40.9 ± 2.2	2.6 ± 0.1	1.4 ± 0.3	0.60 ± 0.13	0.40 ± 0.09	33.5 ± 3.7	6.3 ± 0.3
	Endosperm							
(1)	0.34 ± 0.07	23.2 ± 0.1	0.8 ± 0.2	1.2 ± 0.2	<0.18	0.24 ± 0.02	27.8 ± 1.8	4.3 ± 0.4
(2)	0.35 ± 0.03	18.3 ± 0.7	1.1 ± 0.2	0.6 ± 0.1	0.30 ± 0.03	0.70 ± 0.30	22.7 ± 1.1	2.9 ± 0.1
(3)	0.17 ± 0.03	24.5 ± 0.7	0.8 ± 0.1	0.8 ± 0.1	<0.18	0.37 ± 0.12	14.2 ± 1.8	3.1 ± 0.1
(4)	0.40 ± 0.01	31.6 ± 0.2	1.7 ± 0.1	1.1 ± 0.3	<0.18	0.40 ± 0.07	21.9 ± 1.5	5.1 ± 0.4
(5)	0.60 ± 0.06	28.3 ± 0.5	1.1 ± 0.1	1.2 ± 0.5	<0.18	0.34 ± 0.05	20.0 ± 0.8	4.9 ± 0.1
	Feed							
(1)	0.61 ± 0.02	73.6 ± 2.8	2.4 ± 0.1	4.5 ± 1.1	0.24 ± 0.04	0.59 ± 0.13	68.3 ± 6.3	12.1 ± 0.7
(2)	1.20 ± 0.06	128.8 ± 8.6	4.4 ± 0.7	1.8 ± 0.6	0.21 ± 0.02	0.64 ± 0.02	70.5 ± 3.8	20.0 ± 2.5
(3)	0.30 ± 0.04	74.1 ± 7.6	1.9 ± 0.3	1.8 ± 0.4	0.21 ± 0.07	0.85 ± 0.22	38.7 ± 1.5	7.9 ± 1.2
(4)	0.75 ± 0.03	66.9 ± 0.3	4.0 ± 0.4	1.5 ± 0.1	0.40 ± 0.15	0.65 ± 0.16	85.1 ± 3.7	10.8 ± 0.3
(5)	1.00 ± 0.02	49.9 ± 4.6	1.9 ± 0.1	1.9 ± 0.9	0.27 ± 0.07	0.39 ± 0.04	41.8 ± 1.8	8.2 ± 0.2
	Bran							
(1)	0.83 ± 0.08	48.9 ± 1.5	2.6 ± 0.1	1.7 ± 0.2	0.44 ± 0.05	0.29 ± 0.05	45.2 ± 1.2	15.0 ± 0.5
(2)	0.97 ± 0.06	42.8 ± 2.8	2.3 ± 0.2	1.0 ± 0.4	1.53 ± 0.39	0.47 ± 0.09	33.7 ± 3.5	11.6 ± 0.4
(3)	0.69 ± 0.02	62.5 ± 1.0	2.6 ± 0.2	1.2 ± 0.1	0.69 ± 0.10	1.37 ± 0.06	34.7 ± 2.4	17.5 ± 0.2
(4)	1.73 ± 0.02	45.8 ± 1.4	4.2 ± 0.1	1.0 ± 0.4	0.37 ± 0.05	0.29 ± 0.08	36.3 ± 0.3	18.3 ± 1.5
(5)	1.90 ± 0.12	38.8 ± 1.7	2.0 ± 0.2	1.0 ± 0.4	0.40 ± 0.01	0.35 ± 0.16	20.6 ± 3.5	15.9 ± 0.4

(continued)

TABLE 50. (continued)

Grain source	Metals							
	Cd	Zn	Cu	Ni	Pb	Cr	Fe	Mn
	--------------------	--------------------	--------------------	mg/kg (dry weight)	--------------------	--------------------	--------------------	--------------------
					Germ			
(1)	1.38 ± 0.16	210.6 ± 12.4	6.6 ± 0.3	7.4 ± 0.4	0.25 ± 0.02	0.67 ± 0.26	98.9 ± 0.4	30.8 ± 0.6
(2)	1.57 ± 0.05	156.5 ± 3.3	5.7 ± 0.1	3.6 ± 0.4	0.35 ± 0.02	0.61 ± 0.07	82.4 ± 1.2	25.3 ± 0.4
(3)	0.73 ± 0.11	207.4 ± 1.7	5.0 ± 0.2	2.9 ± 0.6	0.30 ± 0.04	0.94 ± 0.41	70.7 ± 6.9	23.7 ± 1.0
(4)	1.76 ± 0.06	150.7 ± 4.1	9.0 ± 0.6	3.1 ± 0.3	0.37 ± 0.02	0.47 ± 0.04	80.8 ± 4.0	23.7 ± 1.0
(5)	3.20 ± 0.16	144.8 ± 8.5	6.2 ± 0.9	3.9 ± 0.6	0.29 ± 0.06	0.98 ± 0.40	82.1 ± 2.9	27.0 ± 1.3

a/ Corn grain was obtained from a commercial hybrid grown at two locations (1), (2) and three single-crosses (3) B73 x Oh545, (4) R802A x R806, and (5) FRMo17 x FR14A grown at the same location. Locations were fields of strip-mined spoil amended with sewage sludge.

TABLE 51. CONCENTRATIONS OF Ca, Mg, AND P IN WHOLE CORN KERNELS AND FRACTIONS OBTAINED FROM A DRY MILLING OPERATION.*

Grain source	Element		
	Ca	Mg	P
	-------------------mg/kg (dry weight)--------------------		
		Whole kernels	
(1)	38.0 ± 6.0	1,430 ± 60	3,220 ± 142
(2)	38.0 ± 8.5	1,470 ± 40	3,674 ± 85
(3)	44.0 ± 6.0	1,540 ± 40	3,076 ± 52
(4)	56.1 ± 6.1	1,590 ± 70	3,384 ± 121
(5)	56.0 ± 6.2	1,610 ± 70	3,800 ± 157
		Endosperm	
(1)	26.4 ± 3.4	560 ± 40	1,299 ± 29
(2)	34.5 ± 5.1	420 ± 10	955 ± 28
(3)	9.5 ± 2.5	860 ± 50	1,744 ± 123
(4)	13.1 ± 1.8	1,090 ± 20	2,424 ± 56
(5)	21.5 ± 2.5	1,150 ± 50	2,673 ± 95
		Feed	
(1)	44.8 ± 1.8	1,180 ± 80	4,609 ± 67
(2)	81.7 ± 19.1	4,330 ± 570	10,189 ± 174
(3)	36.2 ± 6.5	2,110 ± 20	4,748 ± 105
(4)	64.1 ± 6.3	2,280 ± 80	5,387 ± 148
(5)	41.1 ± 2.5	2,060 ± 80	5,372 ± 171
		Bran	
(1)	98.4 ± 2.6	980 ± 60	1,902 ± 75
(2)	126.5 ± 9.3	750 ± 30	1,422 ± 35
(3)	129.1 ± 2.6	1,250 ± 30	2,194 ± 56
(4)	168.1 ± 2.6	990 ± 40	1,919 ± 52
(5)	83.3 ± 4.3	840 ± 60	1,616 ± 71
		Germ	
(1)	76.8 ± 9.0	6,700 ± 100	16,990 ± 400
(2)	95.1 ± 1.4	5,740 ± 130	14,177 ± 134
(3)	72.5 ± 5.2	5,890 ± 30	13,667 ± 307
(4)	99.3 ± 3.9	5.720 ± 90	13,893 ± 868
(5)	85.8 ± 9.1	6,970 ± 370	18,354 ± 660

* Corn grain was obtained from a commercial hybrid grown at two locations (1), (2), and three single-crosses (3) B73 x Oh545, (4) R802A x R806, and (5) FrMo17 x FR14A, grown at the same location. Locations were fields of strip-mined spoil bank amended with sewage sludge.

endosperm fractions contained 20 to 58 and 25 to 48% of total grain Ca and Mg, respectively. These results suggest that amounts of Ca and Mg retained in the endosperm fraction of dry milled corn grain were related inversely. Only about 24% of the total P in whole kernels of grain from the hybrid grown at two locations was retained in the endosperm fraction. In comparison, about twice as much P remained in the endosperm fraction of grain from the three single-crosses selected for differences in capacities to accumulate Cd and grown in the same field.

Comparing concentrations in the endosperm (Table 50) with those in the degermed fraction (Table 49) of grain from the three single-crosses grown on strip-mined lands, it appears that the former contains less Cd, Pb, and Cr, and more Zn and Fe than the latter. Concentrations of Cu, Ni and Mn in the endosperm fraction obtained by dry milling were similar to those in degermed corn kernels. Some of the difference may have been due to differences in harvesting. Grain used for the degerming study was hand harvested in September while grain used for the dry milling study was harvested with a combine in December.

Concentrations of Selected Elements in Wheat Grain Fractions Separated by Dry Milling--

Results presented in Table 52 and 53 show that sludge treatments caused increased concentrations of Cd, Zn, Cu, Ni, Fe, Ca, Mg, and P in wheat grain. Milled samples of the grain yielded approximately 66, 21, and 13%, respectively, of flour, shorts and bran. Flour contained 29, 14, 28, 13, 55, 41, 43, 15, 35, 12 and 18%, respectively, of the total amounts of Cd, Zn, Cu, Ni, Pb, Cr, Fe, Mn, Ca, Mg and P in whole wheat grain. Relative amounts of Zn, Ni, Fe, Mn and Ca in flour tended to decrease when concentrations of these elements were enhanced in wheat grain as a result of higher sludge loading rates.

Except for the endosperm and oil fractions from corn and flour from wheat, insignificant amounts of other fractions are used to prepare human foods. After oil is expelled from the germ practically all of the germ-cake and remaining fractions are sold as animal feeds. Results from this study suggest that practices which enhance concentrations of inorganic elements in grains may lead to relatively high concentrations in fractions used in animal rations with only nominal increases in portions of grain kernels consumed directly by man. It is unlikely that higher concentrations of inorganic elements of corn and wheat grain than those reported here will be produced as a result of using biologically stabilized municipal sewage sewage sludges as fertilizers and soil amendments. Corn single-crosses having high grain-Cd contents were specifically selected for the capacity to accumulate Cd and even the half-rate application of sewage sludge where wheat was grown provided nitrogen at levels considered to be too high for the protection of ground-water against contamination with excessive NO_3-N concentrations. Used to supply agronomic rates of N fertilization, there is no evidence that biologically stabilized sewage sludges will present a health hazard to man or animals consuming the grain containing the resulting enhanced concentrations of essential and nonessential inorganic elements.

TABLE 52. CONCENTRATIONS OF METALS IN WHOLE AND FRACTIONS OF WHEAT KERNELS HARVESTED FROM (1) CONTROL PLOTS AND PLOTS IRRIGATED WITH (2) INTERMEDIATE AND (3) MAXIMUM SLUDGE LOADING RATES.

Grain source	Metals							
	Cd	Zn	Cu	Ni	Pb	Cr	Fe	Mn
	mg/kg (dry weight)							
				Whole kernels				
(1)	0.40 ±0.05	51.1 ± 6.3	4.3 ±0.5	0.8 ±0.2	0.31 ±0.06	0.8 ±0.3	40.7 ±3.0	46.2 ±4.0
(2)	2.61 ±0.22	102.1 ± 4.3	5.6 ±0.2	4.4 ±0.9	0.41 ±0.14	0.9 ±0.5	46.5 ±5.3	32.6 ±1.3
(3)	3.44 ±0.[illegible]5	131.6 ±14.8	7.0 ±0.9	17.7 ±0.5	0.31 ±0.05	0.5 ±0.2	48.6 ±4.2	38.7 ±6.0
				Flour				
(1)	0.11 ±0.01	14.6 ± 2.0	2.0 ±0.1	1.4 ±0.1	0.26 ±0.03	0.51 ±0.14	30.8 ±3.3	13.3 ±0.2
(2)	1.16 ±0.03	20.8 ± 0.7	2.3 ±0.1	1.1 ±0.1	0.24 ±0.03	0.54 ±0.03	31.9 ±6.1	9.2 ±0.5
(3)	1.48 ±0.01	21.2 ± 4.8	2.9 ±0.1	2.6 ±0.4	0.34 ±0.03	0.32 ±0.05	25.8 ±0.9	9.5 ±0.2
				Shorts				
(1)	0.79 ±0.04	141.5 ± 1.9	11.4 ±0.2	2.4 ±0.1	0.55 ±0.05	0.42 ±0.07	120.4 ±6.5	108.3 ±1.1
(2)	5.02 ±0.08	243.6 ± 1.7	12.8 ±0.1	9.9 ±0.2	0.54 ±0.03	0.45 ±0.10	110.0 ±5.7	71.7 ±0.9
(3)	6.57 ±0.08	269.7 ± 3.9	13.5 ±0.1	31.2 ±0.1	0.61 ±0.03	0.58 ±0.14	127.4 ±2.9	73.1 ±1.0
				Bran				
(1)	0.58 ±0.01	165.2 ± 2.6	12.7 ±0.2	7.2 ±0.2	0.42 ±0.07	0.52 ±0.03	137.3 ±2.8	117.7 ±3.6
(2)	6.24 ±0.05	273.4 ± 1.3	12.6 ±0.2	15.6 ±0.2	0.49 ±0.03	0.32 ±0.04	118.4 ±9.2	62.6 ±2.0
(3)	8.14 ±0.10	368.0 ± 6.6	15.3 ±0.1	48.6 ±0.2	0.35 ±0.05	0.57 ±0.25	162.9 ±7.0	88.7 ±0.9

TABLE 53. CONCENTRATIONS OF Ca, Mg, AND P IN WHOLE AND FRACTIONS OF WHEAT KERNELS HARVESTED FROM (1) CONTROL PLOTS AND PLOTS IRRIGATED WITH (2) INTERMEDIATE AND (3) MAXIMUM SLUDGE-LOADING RATES.

Grain source	Element		
	Ca	Mg	P
	mg/kg (dry weight)		
		Whole kernels	
(1)	249 ± 9.8	1,790 ± 80	3,918 ± 140
(2)	435 ± 10.0	1,860 ± 50	5,381 ± 64
(3)	778 ± 19.8	2,080 ± 170	6,349 ± 180
		Flour	
(1)	169 ± 15.1	340 ± 30	1,265 ± 34
(2)	228 ± 1.4	330 ± 10	1,408 ± 94
(3)	287 ± 7.8	370 ± 10	1,572 ± 43
		Shorts	
(1)	564 ± 10.4	3,690 ± 140	8,573 ± 230
(2)	826 ± 28.9	3,720 ± 20	9,733 ± 366
(3)	1,200 ± 54.9	3,730 ± 180	10,258 ± 71
		Bran	
(1)	595 ± 6.5	6,240 ± 20	12,489 ± 374
(2)	1,037 ± 14.2	6,400 ± 50	15,845 ± 67
(3)	1,742 ± 10.4	7,190 ± 60	18,191 ± 261

If all the municipal sewage in the United States was treated to secondary level and the sludge used, at agronomic rates, to grow corn and wheat, only about 868,000 hectares of land would be affected in any single year by the practice. About 28.4 and 26.5 million hectares were devoted to corn and wheat production, respectively, in 1977. Considering that the maximum amount of these two grain crops that could possibly be affected by sewage sludge utilization is about 0.5% of the total, marketing operations insure blending of grain, and dry milling will reduce above normal concentrations of some heavy metals in grains by 50% or more in fractions used for direct human consumption, any potential threat to human health is negligible. Concentrations of many essential elements in grain were increased by sludge fertilization and these may contribute to improved nutrition for both animals and man.

EFFECTS OF SLUDGE APPLICATIONS ON ORGANIC FRACTIONS OF BLOUNT SILT LOAM SOIL

General Description

The study reported here was undertaken to gain more precise information regarding the fate and the nature of the organic fraction of anaerobically digested sludge in the soil environment. Sources of input and loss of some organic fractions to the soil-water system were measured. This information can be useful in determining loading rates and practical system designs.

The studies were carried out using six Blount silt loam plots from the 44-plot lysimeter facility described in detail by Hinesly et. al. (1974) and from which more recent results have been obtained as reported in Section 1 of this report.

Soil samples were collected in May 1975 to a depth of 76 cm as discussed earlier in Section 1. Analytical results for all soils are expressed on an oven dry basis. Leachate water samples from the plots were collected at the beginning of each drainage event occurring from May 1974 through April 1975. Filterable solids were removed with 0.45 μ membrane filters and the samples were stored at 1°C.

Total organic carbon in soils was determined by the wet oxidation method described by Allison (1965). Water and sludge organic carbon levels were measured by reductive pyrolysis using a Dohrman DC-50 Organic Carbon Analyzer (Takahasi et. al., 1972).

Water-extractable carbon in solids was measured by shaking 25 g of soil that had been maintained at field moisture level with 50 ml of deionized water for 24 hours. Extracts were obtained by centrifugation at 1500 rpm decantation and filtration through 0.45 μ membrane filters. Organic carbon in the filtrate was measured by the method used for leachate water.

Soils (5 g) or freeze-dried (0.1 g) were homogenized in 15 ml of $3\underline{N}$ H_2SO_4 in a Waring blender. Homogenized samples were washed into glass beakers with an additional 15 ml of $3\underline{N}$ H_2SO_4, covered with watch glasses and hydrolyzed for 24 hours at 85°C. Hydrolysates were filtered while hot through pre-washed fiberglass filter paper and then diluted to 100 ml with deionized water. Carbohydrate carbon in hydrolysates and filtered leachate samples were determined colorimetrically by the phenol-sulfuric acid method of Dubois et. al. (1956), using glucose solutions as standards.

Oil and grease carbon in water samples was determined by the method of the U.S.E.P.A. (1974). By this method, oils and grease are defined as those compounds which are extractable in Freon 113 and absorb in the aliphatic C-H stretching region at 2930 cm^{-1}. It is, therefore, applicable to the determination of hydrocarbons, vegetable oils, animal fats, waxes, soaps, greases and related matter (U.S.E.P.A. 1974). This method was also adapted for use with soil and sludges. Soils (5 g) and freeze-dried sludge (1 g) were refluxed with 30 ml of Freon 113 for 12 hours in micro-sohxlet extractors and the resulting extracts were diluted to 50 ml before analysis.

For organic nitrogen determinations, approximately 0.5 g of soil, 1 ml of sludge or 50 ml of water were weighed into micro-Kjeldahl flasks. Soils and sludges were diluted to 25 ml with deionized water, whereas leachate waters remained undiluted. Potassium phosphate buffer at pH 7.4 (2 ml) was added and the volume of solution was reduced to approximately 5 ml under low heat to remove free ammonia. Remaining solutions were digested with 5 ml of H_2SO_4-K_2SO_4-$HgSO_4$ digested reagent (10 ml for solids), steam distilled into boric acid, and measured titrametrically for ammonia nitrogen as described by Taras et. al. (1971).

Discussion of Results

Sludge Components--

Concentrations of some organic constituents of two sludges, sampled in triplicate and subsequently applied on Blount silt loam lysimeter plots during the 1975 growing season, are reported in Table 54. The total organic-C content of 26.6% (dry wt. of sludge solids) was similar to average concentrations found in sludges from the MSD of Chicago Southwest wastewater treatment plant. The most noticeable feature of the organic fractionation was the high level of oil- and grease-C which made up over 31% of the total organic-C. In contrast, only about 7% of the total organic-C was carbohydrate-C.

Organic Fractions in Soil--

Data appearing in Table 55 for Blount silt loam profiles and all following tables are means of results from the three control and three maximum-sludge-treated plots. There were significant differences between controls and sludge-treated plots for all fractions at the 0 to 15 and 15 to 30 cm depths and for water-extractable carbon at the 61 to 76 cm depth. Because of mixing associated with seed bed preparation, it could not be concluded that the significant increases at the 15 to 30 cm depth for all fractions were due to illuvation. The significant increase in water-extractable organic-C from 10.4 mg/kg to 17.1 mg/kg at the 61 to 76 cm depth reflected the increase in total organic-C in drainage waters as shown in Table 56, which will be discussed further in a later section. It was apparent that some movement through the soil profile was associated with sludge treatment. However, the

TABLE 54. ORGANIC CONSTITUENTS OF SLUDGES FROM ANAEROBIC DIGESTORS AT THE SOUTHWEST SEWAGE TREATMENT PLANT OF THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO WHICH WERE APPLIED TO LYSIMETER PLOTS IN 1975.

Component	Mean concentration
	--%--
Total solids	2.84 ± 0.34
	--% total solids--
Volatile solids	48.55 ± 2.06
Total organic-C	26.60 ± 1.18
Carbohydrate-C	1.86 ± 0.06
Oil & grease-C	8.28 ± 0.10
Organic-N	3.40 ± 0.24

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TABLE 55. ORGANIC FRACTIONS AS PERCENT OF TOTAL ORGANIC CARBON AND CARBON TO NITROGEN RATIOS IN BLOUNT SILT LOAM CONTROL AND MAXIMUM-SLUDGE-TREATED LYSIMETER PLOTS.

Depth cm	Water extractable C			Carbohydrate C			Oil & grease C			Organic-C/N		
	0	Sludge	LSD.05	0	Sludge	LSD.05	0	Sludge	LSD.05	0	Sludge	LSD.05
	% TOC									Ratios		
0-15	0.239	0.242	n.s.	18.9	10.9	2.8	1.67	11.90	3.02	9.36	10.80	0.94
15-30	0.360	0.423	n.s.	19.9	18.9	n.s.	0.80	1.38	0.46	9.11	9.98	n.s.
30-46	0.585	0.478	n.s.	28.0	26.2	n.s.	0.90	0.89	n.s.	7.32	7.23	n.s.
46-61	0.394	0.461	n.s.	27.1	22.8	3.6	0.70	0.73	n.s.	7.33	7.71	n.s.
61-76	0.219	0.349	.055	22.0	19.7	n.s.	0.68	0.69	n.s.	8.16	7.78	n.s.

absence of significant differences for carbohydrate-C, oil- and grease-C and organic-N indicate that no gross accumulation of organic compounds in the lower depths took place over the six-year period. Lack of ability to detect significant differences for these fractions was probably due in part to the fact that water-soluble organic-C was a very small proportion of the total organic-C throughout the soil profile (Table 55).

The most striking change in soil composition due to sludge application was the increase in oil- and grease-C. In the 0-15 cm depth this fraction increased from 1.67 to 11.93% of the total organic-C. In terms of the absolute levels reported in Table 54, total organic-C, water-extractable organic-C, carbohydrate-C and organic-N varied only from 1.4 to 2.5 times that in the control plots, whereas oil- and grease-C increased approximately 17.8 times. The effect of the accumulation of these hydrophobic compounds on soil physical characteristics, on a long term basis, is questionable. Hillel and Berliner (1974) have shown that presence of a top layer of hydrophobic aggregates can either increase or decrease water infiltration, depending on the size of the aggregates. Reduction in corn germination and yields of 50 to 90% of controls, respectively, were reported by Udo and Fayemi (1975) upon application of 4.2 percent crude oil to soils. Poor growth was attributed to suffocation of the plants caused by exclusion of air by the oil, exhaustion of the oxygen by increased microbial activity, interference with soil-plant-water relationships and toxicity from sulfides and excess available manganese produced during decomposition of the hydrocarbons. No such deterimental effects have been observed in these studies.

The significant increase in the ratio of organic-C to organic-N at the 0 to 15 cm depth in the treated plots was an indication of a high rate of mineralization and subsequent loss of organic-N as a result of sludge addition. The C/N ratio of the untreated soil was 9.36 and that of the applied sludge was 7.82. Because the C/N ratio of soil increased to 10.8 with treatment, it is apparent that organic-N was lost from the system at a faster rate than organic-C.

The overall effect of 6 years of sludge additions appeared to have been a shift in the distribution of soil organic compounds towards that of sludge. Carbohydrate-C decreased from 18.9% in the control plots to 10.9% in treated plots, reflecting the relatively low proportion of carbohydrates in the sludge organic matter. The opposite trend was evident in the soil and grease fraction of the soil as a result of the high proportion of this fraction in sludge. This trend did not follow for the added organic-N, however, as discussed previously.

Organic Fractions in Leachate Water--

Results of the fractionation of organic compounds in leachate water collected for all drainage events from May 1974 through May 1975 are shown in Table 56. Rainfall and snow melt during this period resulted in water movement to drainage tiles in sufficient quantity for analysis on only three occasions. Water analyses for other parameters over the previous 6 years

TABLE 56. ORGANIC FRACTIONS IN LEACHATE WATER COLLECTED FROM BLOUNT SILT LOAM DURING THREE DRAINAGE EVENTS IN 1975.

	09 Jan			19 Apr			30 May		
	0	Sludge	LSD.05	0	Sludge	LSD.05	0	Sludge	LSD.05
	mg/l								
Total organic-C	9.9	29.2	1.7	12.5	32.0	1.5	9.4	20.3	1.2
Carbohydrate-C	1.40	7.14	1.41	0.86	12.46	1.40	2.91	4.48	1.40
Oil & grease-C	0.21	0.85	0.14	0.38	0.86	0.19	0.48	0.57	n.s.
Organic-N	0.48	0.78	0.18	0.48	0.77	0.17	0.58	0.67	n.s.

indicated that log-normal distributions gave the clearest representation of parameters (see Section 1). Therefore, all means given in Table 56 are geometric means and LSD's were calculated assuming log-normal distributions.

A marked decline in the organic-C level of leachate waters from sludge-treated plots for the May 30 drainage event is evident (Table 56). It is possible that the reduction in organic-C was due to dilution effect. At this sampling period, the longest time had elapsed since the last application of sludge during the previous fall. This data also falls in a period when soil moisture levels and temperature were optimal for microbial metabolism to take place.

All organic fractions shown in Table 56 were significantly increased as a result of sludge treatments except oil- and grease-C and organic-N for the May 30 drainage event. The 2- and 3-fold increase of total organic-C levels over all sampling dates reflected the increase in soil organic-C (2.4 times the concentration in control plots).

Because oil and grease compounds are hydrophobic, the significant increase in leachate oil and grease levels due to sludge treatment was somewhat surprising. This may be better interpreted in light of the infrared absorption method used for the analysis. Short and medium chain length fatty acids and detergents with pKa values less than 5 will be negatively charged and more water soluble at the pH of the leachate water (7 to 8). The extraction with Freon was made at pH 2, at which ionization of these compounds was suppressed. Under these circumstances, they became hydrophobic and were partitioned mainly to the Freon phase where they were measured in the extract according to their C-H stretch.

Carbohydrate-C accounted for both the greatest increase of all the fractions as a result of sludge treatment and the greatest proportion of the total organic-C. As shown on Table 57 for both January 9 and April 19 drainage events, carbohydrate-C, as a percent of the total-C, significantly increased as compared to control plots. The proportionate increase did not reflect the sludge composition, since carbohydrate-C was only a small portion (7%) of the sludge organic-C. This increase may have been due to a relatively greater water solubility of sludge carbohydrates than other organic fractions. More rapid breakdown of polymerized carbohydrates than other fractions was also possible. In either case there was little soil retention mechanism for most carbohydrates which are uncharged or anionic at neutral pH levels. Carbohydrates are therefore likely to move with relative ease through the soil profiles as compared to other fractions. At the same time, they are among the most susceptible of compounds to utilization by soil microflora. There was no significant increase in organic-N for the May 30 drainage event and a very small increase for the other two dates (Table 56).

The weighted average C/N ratio of soil amino acids calculated from studies published by Stevenson (1956) and Young and Mortensen (1958) was approximately 3.1 to 1. Assuming that this ratio was similar to organic-N compounds of the leachate water, an estimate of their C content can be made. Summation of this estimate with the measured C of the other two organic fractions resulted in a total which accounted for only 21 to 55% of the total organic-C among all

TABLE 57. SOME ORGANIC FRACTIONS AS PERCENT OF TOTAL ORGANIC CARBON TO NITROGEN RATIOS IN LEACHATE WATER COLLECTED FROM BLOUNT SILT LOAM DURING THREE DRAINAGE EVENTS IN 1975.

	09 Jan			19 Apr			30 May		
	Check	Sludge	LSD.05	Check	Sludge	LSD.05	Check	Sludge	LSD.05
Carbohydrate-C (%)	14.2	24.4	1.5	6.9	39.0	1.6	30.9	22.1	n.s.
Oil & grease-C (%)	2.1	2.9	1.0	3.0	2.7	n.s.	5.0	2.8	1.6
Organic-N (C/N)	20.9	37.3	1.8	26.3	42.1	2.0	16.1	29.9	1.3

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water samples. Results of ultrafiltration studies in our laboratory indicated that for both control and treated plots, 40 to 50 percent of the total organic carbon was in a polymerized form greater than MW 10,000. Thus, a high portion of these unidentified high molecular weight carbon compounds were probably humic substances. Although no relative increase in high molecular weight carbon compounds was observed, the absolute increase was on the same order as that of the total organic-C. Ogner and Schnitzer (1970) and Ballard (1971) have demonstrated the ability of water soluble humic substances to complex with pesticides and toxic industrial byproducts such as dialkyl phthalates, rendering them more soluble. If such substances are accumulated in the sludge, a mechanism for their transport through the soil profile exists.

The results of this study must be interpreted both in terms of the particular sludge application system used and local humid temperate climatological factors. Under these conditions sludge organic-C oxidizes rather rapidly in the soil. Approximately 60% of the organic-C added over 7 years as a constituent of sludge could not be accounted for in the soil.

A potential problem with long-term high rate applications of anaerobically digested sludge to the soil may result from the accumulation of oil and grease. Although this study has shown a distinct increase in the proportion of oil- and grease-C in the soil as a result of sludge treatment, no adverse effects attributable to this source on crop growth have yet been recorded.

FRACTIONATION OF ORGANIC MATTER CONTAINED IN SLUDGE AND SOIL WITH AND WITHOUT SLUDGE

General Description

Digested sewage sludge increases organic matter contents of soils in proportion to amounts annually applied. After a few years soil organic matter contents change very little with a particular annual application rate, indicating that an equilibrium condition is soon established between amounts added and amounts lost. But because of the inherent variability in sludge organic matter contents, sludge loading rates, and sampling of soils, it has not been possible to determine whether or not all organic constituents of sludge were being decomposed at rates equivalent to their annual additions. Toward obtaining information about the accumulation of refractory organic constituents in soil after several years of annual sludge applications, the organic matter contained in sludge and in sludge-amended and non-amended soil was fractionated according to procedures outlined by Waksman (1930) and Stevenson (1965).

Soil samples collected in 1974 from the control and maximum-sludge-treated plots of the continuous corn study discussed in Section II and samples of sludges, from the MSD of Chicago Southwest wastewater treatment plant and used for irrigation of corn in 1973 and 1974, were analyzed for several organic fractions. The fractions obtained by various treatment schemes were as follows:

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Fraction	Treatment
1. Fats, waxes, oils	Ether extraction
2. Resins	Alcohol extraction
3. Water-soluble polysaccharides	Hot water extraction
4. Hemicellulose	Hydrolysis with 2% HCl
5. Cellulose	Hydrolysis with 80% H_2SO_4
6. Lignin-humus	Analysis of final residue for carbon and nitrogen
7. Protein	Analysis of original sample for nitrogen

For fraction 1, 30 g of soil or 10 g of dried sludge were extracted with 150 ml of ether in a sohxlet apparatus for 24 hours. The ether was evaporated to a small volume, transferred to Vycor crucibles and dried 30 minutes at 100°C. Dry weights were determined before and after the extracts were ashed at 500°C for 24 hours. The net weight loss comprised the fats, waxes and oils and was expressed as % of dry weight of soil.

For fraction 2, dry ether-extracted samples were then extracted with 150 ml of ethanol for 6 hours in the sohxlet apparatus. The alcohol extract was evaporated to a small volume, transferred to crucibles and dried one hour at 100°C. The extracts were then ashed and the results calculated as above to obtain contents of resins.

To determine fraction 3, samples previously extracted by ether-alcohol were extracted with 150 ml distilled water for six hours in the sohxlet apparatus. The extracts were processed as in fractions 1 and 2 with the exception that the residues were dried overnight at 110°C prior to ashing. Contents of water-soluble polysaccharides were calculated from net weight loss due to ashing.

One-half (by weight) of the dried residue remaining after the hot-water extraction was transferred to a 1-liter flask and refluxed for 5 hours with 300 ml of 2% HCl. After cooling, the mixture was filtered with Whatman No. 50 and washed with 2% HCl. The combined filtrate and washings were then adjusted to 500 ml. The content of reducing sugars was determined using the anthrone method (Brink 1960) (Morris 1948) instead of the Fehling method originally specified (Stevenson 1965). Filtrate and distilled water in portions of 1 and 4 ml, respectively, were transferred to 25 x 150 mm screw cap test tubes and 10 mls of 0.2% anthrone in 95% H_2SO_4 was added. Glucose standards were prepared in concentrations ranging from 5-70 ppm. After 15 minutes the samples and standards were compared against a blank containing only water and reagent in a spectrophotometer at 625 nm. The amount of reducing sugars present was reported as the hemicellulose content for Fraction 4.

The residue from Fraction 4 was dried and weighed in an evaporating dish and 5-10 g were transferred to a stoppered 125 ml erlenmeyer flask. After 25 ml of 80% H_2SO_4 was added, the mixture was incubated 2.5 hours at 12°C to 14°C. After incubation, the contents were refluxed with 350 ml of distilled water for 5 hours and filtered. Then the combined filtrates and washings were diluted to 500 ml. Reducing sugars were determined in 5 ml of the extract by the method described above. The amount of reducing sugars was reported as the cellulose content for Fraction 5.

The residue from Fraction 5 was dried and weighed. Then organic carbon and nitrogen contents were determined by dichromate oxidation and Kjeldahl procedures, respectively. Portions of the unextracted samples were also analyzed for organic carbon and total nitrogen by the above methods.

The results of Fractions 1, 2 and 3 were calculated as percent dry weight directly from the net losses due to ashing of the respective extracts. The amounts of hemicellulose in the aliquots were multiplied by 0.9 to account for the loss of water accompanying the polymerization of monosaccharides (Stevenson 1965). The resultant values were multiplied by the appropriate dilution factors to obtain the amount in the original sample. The lignin-humus of Fraction 6 was calculated by subtracting the protein of the final residue (N times 6.25) from the total organic matter (C times 1.724) of the final residue. The protein of Fraction 7 was calculated from the nitrogen analysis of the original sample (N times 6.25).

Discussion of Results

Concentrations of Organic Matter Fractions--

Average concentrations of organic fractions in replicated (4) soil and sludge samples are presented in Table 58. Relative to soils, sludges contained higher amounts of protein (Fraction 7), fats, waxes, and oils (Fraction 1), and lignin-humus (Fraction 6), where the latter two fractions were about equal in concentrations. In Blount silt loam soil, subjected to normal management practices, concentrations of protein (Fraction 7) and lignin-humus (Fraction 6) were about equal and both fractions were present in considerably higher concentrations than other fractions. Annual applications of digested sludge markedly increased concentrations of all organic fractions in soils, but concentrations of polysaccharides, hemicellulose, and cellulose were affected least. Considering the distribution of concentrations as a percent of the total organic matter content, as shown in Table 59, it appears that except for contents of fats, waxes, and oils annual sludge applications did not materially affect the constitution of soil organic matter. Sludge applications markedly increased the proportion of fats, waxes, and oils in soil organic matter, perhaps at the expense of all other fractions except resins and lignin-humus contents. Estimating the amounts of fats, waxes and oils applied as a constituent of sludge over a 6 year period and amounts that have accumulated in soil during that time shows that about one-third of the total amounts added have been lost from the soil surface. Thus, an equilibrium will eventually be reached between annual applications of sludge-borne fats, waxes, and oils and amounts lost from the soil. Probably this equilibrium already exists and these compounds are unlikely to reach proportions in soils that would adversely affect their productivity.

TABLE 58. CONCENTRATIONS OF TOTAL AND MAJOR FRACTIONS OF ORGANIC MATTER IN SLUDGES AND 1974 SOIL SAMPLES FROM BLOUNT SILT LOAM PLOTS WHERE ZERO AND MAXIMUM AMOUNTS OF SLUDGE HAD BEEN ANNUALLY APPLIED DURING THE PREVIOUS 6 YEARS.*

Fraction	1973 Sludge	1974 Sludge	Sludge application rate	
			0	Maximum
1. Fats, waxes and oils	8.84	7.35	0.04	0.42
2. Resins	1.71	3.16	0.10	0.29
3. Water-soluble polysaccharides	1.44	5.54	0.19	0.30
4. Hemicellulose	1.83	2.30	0.38	0.71
5. Cellulose	1.54	1.24	0.12	0.21
6. Lignin-humus	7.51	5.59	0.73	1.69
7. Protein	10.79	15.26	0.80	1.62
Total recovered	33.66	40.44	2.37	5.29
Organic matter (c x 1.724)	44.76	38.53	2.48	5.43
% Recovery	75.21	105.0	95.72	97.38

*Values are percent dry weight of sludge or soil.

TABLE 59. CONCENTRATIONS OF ORGANIC MATTER FRACTIONS IN THE TOTAL ORGANIC MATTER CONTAINED IN SLUDGES AND SOIL.*

Fraction	1973 Sludge	1974 Sludge	Sludge application rate	
			0	Max
1. Fats, waxes and oils	19.75	19.07	1.48	8.68
2. Resins	3.82	8.20	4.03	5.3
3. Water-soluble polysaccharides	3.22	14.38	7.79	5.47
4. Hemicellulose	4.04	5.97	15.45	13.15
5. Cellulose	3.45	3.22	4.98	3.86
6. Lignin-humus	16.78	14.51	29.58	31.11
7. Protein	24.11	39.60	32.41	29.81

*Values are percent dry weight of organic matter.

CONCENTRATIONS OF NITROGEN FRACTIONS IN SLUDGE AND IN SLUDGE-AMENDED AND NON-AMENDED BLOUNT SILT LOAM SOIL

General Description

As observed in the continuous corn study discussed in Section II, maximum sludge applications significantly increased total-N concentrations in Blount silt loam soil each year. But like organic-C contents, total-N levels appeared to approach an equilibrium condition after several years of annual applications. As was the case for organic matter accumulations, sludge loading rates and N concentrations in sludge were too variable from year to year to determine whether or not an equilibrium concentration had been established by sampling soils once each spring. To obtain more information about forms of N in sludge and their accumulation in soils, samples of sludge applied on the continuous corn study [Section II, (1)] and samples of soil from control and maximum-sludge-treated plots were analyzed for various hydrolyzable N fractions according to methods discussed by Bremner (1965).

The hydrolysate was prepared by refluxing 5 g of soil or 0.5 g of sludge (finely ground and oven-dry) with 20 ml of 6 N HCl and two drops of octyl alcohol for 12 hours. The flasks were allowed to cool and the mixtures were then filtered with Whatman No. 50 filter paper and washed with 20 ml of H_2O on a suction apparatus. Combined filtrate and washings were transferred to beakers and chilled in a tray of crushed ice on top of a magnetic stirrer. Hydrolysates were slowly neutralized with 10 N NaOH to approximately pH 5.0. Then the pH was slowly increased to 6.5 with 0.5 N NaOH. Neutralized hydrolysates were transferred to 100 ml volumetric flasks and diluted to volume with distilled water. Reagents, which were specific for each N fraction, were added to 5- or 10-ml (as required) of hydrolysate and N concentrations were determined by the use of steam distillation micro-Kjeldahl equipment.

Results and Discussion

Nitrogen Fractions in Sludge and Soil--

As may be seen in Table 60 sludge contained 2.42% (dry wt.) of hydrolyzable N of which about 30 to 41%, respectively, were hydrolyzable ammonium- and amino acid-N. However, about 27% of the hydrolyzable-N in sludge remained unidentified. Digested sludge contained such low concentrations of hexosamine-N that concentrations of this fraction in soils was not increased by maximum sludge applications. Except for hexosamine-N, concentrations of total and other hydrolyzable fractions in soil were increased by sludge applications. In soil, total hydrolyzable-N concentrations were about 78% of total soil N (as reported in Table 13), regardless of treatment. The major effect of sludge applications on soil was to increase amounts of hydrolyzable-N in the amino-acid fraction at the expense of the hexosamine-N, ammonium-N, and unidentified-N fractions.

TABLE 60. CONCENTRATIONS OF TOTAL AND FRACTIONAL FORMS OF N IN SLUDGE AND SURFACE SOIL (0-15) FROM BLOUNT SILT LOAM CONTROL AND MAXIMUM-SLUDGE-TREATED PLOTS SAMPLED IN 1974.

Fraction	1974 Sludge	Sludge application rates 0	Max
	----------% of soil (dry wt.)-----------		
Total-N (hydrolyzable)	2.42	0.115	0.221
ammonium-N	0.72	0.036	0.062
hexosamine-N	0.07	0.008	0.007
serine-threonine-N	0.19	0.010	0.024
amino acid-N	0.99	0.039	0.096
	-------------% of Total N--------------		
ammonium-N	29.63	30.9	27.83
hexosamine-N	2.85	6.77	2.94
serine-threonine-N	8.01	8.51	11.00
amino acid-N	41.00	33.68	43.35
% Total-N recovered[a/]	73.49	71.35	74.12

[a/] Serine-threonine was included in the amino acid-N fraction for calculations of total-N recoveries.

BIOLOGICAL ACTIVITY IN SOILS AND STRIP-MINE SPOIL WITH AND WITHOUT SLUDGE

General Description

When sludges from plants treating industrial wastewaters are applied on land the ability of soil to bind heavy metals and accumulate them in plant rooting zones raises a serious question as to the influence of the more soluble ones on biological life and activities in soils.

Although various kinds of wastewaters and solids have been applied on land for long periods of time in many areas of the world, apparently too little attention has been given to determine changes in soil microbial populations and metabolitic activity resulting from such operations. Considering the fact that the soil microflora, especially bacteria and fungi, can affect the availability of trace elements needed in plant nutrition and can exert some influence over the concentration levels of trace elements in soil solutions which are toxic to plants, it is surprising that more attention has not been given to this aspect of waste utilization and/or disposal on land (Ehrlich 1971). It has long been recognized that the soil enzyme complex is the center from which the various biocatalytic processes responsible for establishing orderliness in soil systems arise. Simultaneously participating groups of enzymes catalyze the reactions by which excessive accumulation of relatively simple chemical compounds are temporarily polymerized or connected to more complex and less soluble compounds (Kuprevich and Shcherbakova 1966).

The purpose of this work was to determine the effect of the continuous heavy applications of digested municipal sludge to cropland upon the main systematic and physiological groups of soil microflora and enzymic activity.

Samples of soil were collected at various times throughout the year for several years from continuous corn plots on Blount silt loam (Section II, No. 1), lysimeter plots of Blount silt loam, Elliott silt loam, and Plainfield loamy sand (Section I), and continuous corn plots on strip-mined lands (Section II, No. 4) with and without annual sludge applications. Twelve to 24 samples from each plot were collected from the top 15 cm of soil with a stainless steel probe and pooled to form an aggregate sample of approximately 1 kg. Immediately after returning to the laboratory, each of the freshly collected soil samples was thoroughly mixed with a sample splitter and divided into approximately two equal portions of which one was air dried and passed through a 2 mm screen. When samples were extremely wet, as in winter, they were air dried slightly before splitting. Both fresh and air-dry soils were then stored for overnight in polyethylene bags at +4^{o}C. Percent moisture by weight was determined by drying aliquot samples at 110^{o}C for 24 hours. Water holding capacity of the air-dried soil samples was determined according to Pramer and Schmidt (1964).

Total bacterial counts were determined by two methods. The first method employed the PMA agar described by Larkin (1972). The medium contained 15 g of agar, 1 g of Difco peptonized milk and 0.1 g of actidione. The actidione was dissolved in ethanol and diluted ten-fold to yield a 1% solution in 10% aqueous ethanol. The solution was filter sterilized and added to the medium after autoclaving at the rate of one ml per 100 ml of medium. Ten grams of sieved soil at field moisture condition was added to 95 ml of sterile water in 6 oz. bottles and shaken 10 minutes on a mechanical shaker. Serial dilutions were made with sterile water to yield a 10^{-4} to 10^{-6} dilution of soil. Pour-plates were made by transferring 1 ml of the 10^{-6} dilution of soil to sterile petri dishes and added the melted and cooled sterile medium. After the plates had solidified, a layer of melted sterile 2% agar was poured on top of the PMA agar to prevent excess growth of spreading organisms. The plates were incubated 10 days at 30°C. After incubation, the colonies were counted and the results were expressed as the number of colonies produced per gram dry weight of soil.

The second medium for total bacteria determinations was described by Zvyagintsev (1968) and consisted of the following: H_2HPO_4, 1g; yeast extract, 1g; $FeCl_3$, 0.01g; KNO_3, 1g; $MgSO_4$, 0.5g; $CaCl_2$, 0.2g; and NaCl, 0.1g dissolved in 1000 ml of distilled H_2O and adjusted to a pH value of 6.8, plus a specially prepared soil extract. The soil extract was prepared by suspending 500 g of soil in 1500 ml of distilled H_2O and autoclaving for 20 minutes at 1.2 atm. After autoclaving, the soil suspension was filtered by suction through Whatman No. 2 filter paper mounted in a Büchner funnel and the volume of filtrate brought up to 200 ml with distilled H_2O. The basic medium was mixed with soil extract in 1:1 ratio, and agar was added in amounts equivalent to 2 percent of the mixture, then sterilization was repeated. A specific soil extract was made from samples of soil representing each of the control and three sludge treatments. All inoculations with the soil suspension were made by spreading on the surface of the agar medium with a bent glass rod. Incubations were carried out at 28°C for 6-7 days. Results were expressed on an oven-dry basis.

For the determination of aerobic spore-forming bacteria (F.E. Clark 1965), 10 ml of the 10^{-3} or 10^{-4} soil dilution, as discussed above (first method for total bacteria), was transferred to a sterile, capped test tube and heated 10 minutes at 80-85°C with intermittent agitation. After cooling, 1 ml was used to make pour-plates with Difco nutrient agar. After the medium had solidified, an overlay of 2% agar was applied as also described above. The inoculated plates were incubated 48 hours at 30°C. After incubation the colonies were counted and the results were expressed as the number of colonies produced per gram dry weight of soil.

The estimation of soil fungi was made with rose bengal-streptomycin agar (Martin 1950, Menzies 1965). This medium contains; 5 g of Difco peptone, 10 g dextrose, 20 g agar, 1 g KH_2PO_4, 50 mg $MgSO_4$ and 30 mg of streptomycin per liter. The streptomycin was dissolved separately in 10 ml of distilled water, filter sterilized and added to the medium after autoclaving. The medium was inoculated by transferring 0.1 ml of a 10^{-3} soil dilution onto previously poured plates and spreading the inoculum with a glass rod dipped in ethanol and flamed. The plates were incubated 3 days at 30°C. After incubation the typical fungal colonies were counted and the results were expressed as the number of colonies produced per gram dry weight of soil.

Dextrose-nitrate agar as described by F.E. Clark (1965) was used for the enumeration of actinomycetes. The medium contained; 1 g of dextrose, 0.1 g KH_2PO_4, 0.1 g $NaNO_3$, 0.1 g $MgSO_4$ and 15 g of agar per liter. The medium was autoclaved, poured into petri dishes, allowed to solidify, and inoculated by the spreader technique with 0.1 ml of a 10^{-3} dilution of soil. The plates were incubated 7 days at 30°C. After incubation the actinomycetes colonies were counted and the results were expressed as the number of colonies per gram dry weight of soil.

The number of azotobacter in the majority of soil samples was determined by the use of Jensen's medium (Brown 1962). This medium contains; 5 g of glucose, 0.2 g $MgSO_4$, 0.04 g $FeSO_4$, 5 g Na_2MoO_4, 0.15 g $CaCl_2$ and 15 g of agar per liter. After autoclaving the medium, 10 ml of previously sterilized solution of 8% K_2HPO_4 was added per liter. The medium was poured into culture dishes and allowed to sit overnight. The plates were incubated 7 days at 30°C. After incubation the characteristic azotobacter colonies were counted and the results were expressed as the number of colonies per gram dry weight of soil. For several 1974 samples the agar plate method with sucrose-mineral salts medium as described by Clark (1965) was used to obtain Azotobacter ssp. counts. Inoculations were made by using a multipoint metal inoculator (Beech et. al., 1955; Smith 1961). These results were expressed as percent positive of total inoculations per plate.

The culture medium with brom thymol blue and asparagin was used to obtain counts of denitrifying microorganisms (Timonin 1947). The medium, solidified by the addition of agar in amounts equivalent to 2 percent of its weight, was inoculated with a multipoint metal inoculator (Beech et. al., 1955; Smith 1961). Results were expressed as percent positive of the total inoculations per plate.

Soil amylase activity was determined by the method described by Hoffman and Hoffman (1955). Toluene (1 ml) was added to 10 g of soil in a 6 oz. bottle and mixed well. After 10 minutes, 10 ml of 1% soluble starch solution and 20 ml of modified universal buffer (pH 5.5) were added. Modified universal buffer was prepared as described by Skujins et al. (1962). The contents of the bottle were mixed and incubated 48 hours at 30°C. After incubation the bottles were heated 15 minutes to 100°C in steam to stop all enzyme activity. Distilled water was added to bring the total volume to 100 ml from which 10 ml of the suspension was centrifuged. Reducing sugar content of the supernatant was determined by the Somogyi-Nelson method (N. Nelson 1940). Results obtained from soil samples incubated without substrate were subtracted from the corresponding samples incubated with substrate. The results were expressed as nanomoles of reducing sugar liberated per gram dry weight of soil per hour (nM maltose/g/hr).

Soil catalase activity was measured by the method of Johnson and Temple (1964). Soil (2g), water (40ml) and 5 ml of 0.3% H_2O_2 were combined in 6 oz. screw-cap bottles and incubated 20 minutes at room temperature with constant skaking. After incubation the remaining peroxide was stabilized by adding 5 ml of 3N H_2SO_4. The soil suspension was centrifuged and 25 ml of supernatant was titrated with 0.02N $KMnO_4$. The initial concentration of peroxide was determined by titration of a blank with all ingredients except soil. The amount of peroxide decomposed was found by subtraction and the results were expressed as micromoles of H_2O_2 decomposed per gram dry weight of soil per minute. To determine the amount of nonenzymatic catalysis of H_2O_2, duplicate samples were heated in an autoclave 30 minutes at 1 atm. pressure. Results obtained for heated samples were subtracted from corresponding unheated samples to estimate the actual amount of biological catalase activity.

Soil cellulase activity was determined by the method of Pancholy and Rice (1973). Toluene (1 ml) was added to 10 g of soil in a 6 oz bottle and mixed well. After 10 minutes, 20 ml of 1% carboxymethylcellulose and 20 ml of modified universal buffer (pH 5.5) were added. The contents of the bottle were mixed and incubated 48 hrs at 30°C. After incubation the amount of glucose released on hydrolysis of cellulose was determined as described above for the amylase activity measurement. Results were expressed as nM glucose/g/hr of soil.

Soil dehydrogenase activity was determined by the method described by Galstyan (1962). The results were expressed in µg TPF/24h/g of soil, where TPF is an abbreviation for 2,3,5-Triphenyl formazan.

Soil invertase activity was determined by two different methods. The first was a gravametric copper method (Kuprevich and Scherbakova 1971). Soil (2g), 8% sucrose solution (15ml), acetate buffer (5ml) (pH 4.9) and 4 drops of toluene were added to a 1 oz snap top vial. The vials were shaken well and incubated 24 hours at 30°C. After incubation the vials were heated to boiling to stop all enzyme activity. After cooling, a few granules each of Cyanamid Aeroflac 3171 and Superflac 16 were added and the vials shaken by hand for 30 seconds and allowed to stand 15 minutes. Then 8 ml of the clear supernatant was transferred to a 30 ml erlenmeyer flask which contained a single boiling chip. Fresh Fehlings solution (6ml) was added and the contents heated to boiling for 2 minutes. After cooling one hour, the supernatant was carefully removed with suction and the precipitate washed twice with hot distilled water. The precipitate was dried at 90°C to constant weight and the yield of Cu_2O calculated. The amount of reducing sugar present was determined from a standard table of copper oxide equivalents (N.A. Lange 1946). The results were expressed as milligrams of reducing sugar produced per gram dry weight of soil. The second and preferred method for the determination of soil invertase activity is described by Hoffman and Paulauf (1965). Soil (10g), 2% sucrose solution (10ml) and 10 ml of modified universal buffer (pH 5.5) were combined in a 6 oz bottle. The contents were mixed and incubated 3 hours at 30°C. The amount of reducing sugars released on hydrolysis as sucrose was determined by the method of Somogyi and Nelson as outlined by Clark (1969). Results were expressed as nM glucose/g/hr.

Soil protease activity was determined by incubation of soil with gelatin as a substrate (Hoffman and Teicher 1957). Soil (10g), $CaCO_3$ (0.5g) and 2 ml of toluene were combined in 6 oz bottles and mixed well. To this mixture, 20 ml of 2% gelatin and 20 ml of distilled water was added to duplicate samples. The samples were mixed and then incubated 24 hours at 30°C. After incubation, water was added to bring the total volume to 100 ml from which 10 ml aliquots were withdrawn and centrifuged. The amount of amino-N released was determined by reacting the supernatant with copper phosphate suspension and determination of bound copper (Beauchene 1955). Copper phosphate suspension was prepared by mixing previously dissolved solutions of 28 g of $CuCl_2 \cdot 2H_2O$ in 500 ml of water and 68.5 g of $Na_3PO_4 \cdot 12H_2O$ in 1000 ml of water. The precipitate was centrifuged, washed twice, and resuspended in 250 ml of borate buffer (pH 9.1). Then 15 g of NaCl was added to the suspension. For the determination of amino-N, 5 ml of copper phosphate suspension was added to 5 ml of sample supernatant and shaken well. The mixture was centrifuged, filtered, and the amount of copper determined after appropriate dilution by atomic absorption spectrophotometry. A standard curve was prepared by reacting 5 ml standards containing 1-12 mg/l glycine with 5 ml of copper phosphate suspension and analyzing as for the sample determinations. The results were expressed as milligrams of amino-N liberated per 100 grams of soil. Results obtained from samples incubated with water instead of substrate were subtracted from the corresponding samples incubated with substrate.

Soil urease activity was determined by the method described by Hoffman and Teicher (1961). Concentrations of ammonia released on hydrolysis of urea was determined with an Orion ammonia electrode. The amount of enzyme releasing 1 mg of NH_4-N per 100 g of soil was assumed to be a unit of enzymic activity.

Soil xylanase activity was determined by the method described by Sorenson (1955). Toluene (1 ml) was added to soil (10g) in a 6 oz bottle and mixed well. After 10 minutes, 10 ml of a 1% aqueous solution of xylan and 10 ml of modified universal buffer (pH 6.5) were added. The contents of the bottle were mixed and incubated 24 hours at 30°C. Treatment and analysis of the suspension was as described for amylase.

The amount of CO_2 evolved from soil was determined by the method described by Cornfield (1961) as a measure of soil microbial respiration. Results have been expressed in mg of CO_2/72h/10g of soil. Measurements of soil repiration on samples collected on July 8, 1974 were accompanied by measurements on a series of a portion of the same soil samples enriched with 2 mg KNO_3 and 100 mg glucose per 10 g of soil.

Results and Discussion

Soil Moisture--

The soil moisture content and water-holding capacity were always positively correlated with the content of organic matter accumulated as a result of sludge applications. The results obtained from extensive studies of digested sludge dewatering on soils (Hinesly 1974) showed that sludge applications did not directly increase the soil moisture content by infiltration processes to any great extent after application. At least the period of time in which soil moisture content is increased is too short to affect microbial metabolism since the infiltration of sludge water proceeds basically in the first day after sludge application and is stopped completely when the moisture content of sludge drops to about 80%. Data obtained from soil samples collected during winter periods show similar higher moisture contents with higher sludge loading rates after sludge applications have been suspended

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for several months. As will be discussed later in this section of the report, available water holding capacities of soils were not increased by sludge applications but moisture contents were increased at tensions of 1/3- and 15 atm.

Total and Spore-forming Bacteria--

Soil microbes can be roughly divided into two types (Alexander 1961). The opportunists (zymogenic) are organisms which have rapid growth, and which compete fiercely for their nutritional needs by maximizing nutrient absorption and assimilation. These organisms are stimulated by addition to the soil of organic matter and of water but when conditions are less than ideal they either die out or become dormant. The persistant type microbes (autochthonous) have much slower growth rates, less complex nutritional needs and continue to survive under a wider variety of environmental conditions. The most commonly used measurement of this soil population it total count. Although the results vary greatly according to the method used, the primary difficulty is to formulate a media which will allow a long incubation time to obtain colonies of the persistent types without subsequent outgrowth by adjacent opportunist. Aerobic spore-forming bacteria are a typical example of an opportunist type organism. Although not all opportunists are able to produce spores, this capability provides a convenient method for estimating this portion of the microbial population.

Results for total bacteria determined by the use of the PMA medium probably reflect potential numbers, whereas those obtained from the use of soil extracts as a growth medium were measurements of active bacterial species (Babiuk and Paul, 1970). By either method, the data in Tables 61, 62, and 63 show rather consistent increases in total bacterial populations with higher sludge application rates. In general, the response of total bacteria to sludge treatment at the maximum level was at least a two-fold increase. Total count determinations in soil from lysimeter plots (Table 62) indicated similar results for the Elliott silt loam and Plainfield loamy sand plots. Values obtained for Blount silt loam soil in lysimeter plots show slightly lower absolute levels and less pronounced treatment effect as compared to results obtained from the long-term continuous corn supplemental plots, but these differences were expected in light of the fact that the lysimeter plots have received less sludge and have better drainage. A comparison of the results on the basis of soil type indicates that Elliott silt loam soil gave consistently higher counts than the Blount, and that counts from the loamy sand plots were always lower than either of the other soil types. These results were directly associated with the moisture retention capacity and organic matter content of the respective soils. It must be emphasized that all of the viable soil bacteria were not counted by this method and that there was not always a distinct relationship between total count and soil fertility. The methods used, however, were the best available and do give a reasonable estimate of the general state of the soil bacterial population.

The aerobic spore count determination is based on the heat resistance of bacterial spores as compared to vegetative cells. Since anaerobic spore-forming organisms were excluded by the method of incubation, these organisms were primarily members of the gram-positive genus "Bacillus". The bacterial spore can survive in the soil indefinitely with vegetative growth occurring

TABLE 61. MOISTURE CONTENT AND BIOLOGICAL ACTIVITY IN SOIL FROM CONTINUOUS CORN PLOTS ON BLOUNT SILT LOAM.*

Soil sampling dates	Sludge application rates				
	0	¼-Max	½-Max	Maximum	α-Level
			Soil moisture (%)		
7-07-72	12.99	14.20	14.37	17.09	.01
9-06-72	16.44	19.24	19.98	21.50	.01
2-20-73	24.64	25.50	25.75	27.87	.01
5-21-73	17.46	17.98	19.33	20.45	.01
8-01-73	7.33	9.05	11.51	15.53	.01
10-18-73	18.79	18.76	19.50	22.34	.01
2-20-74	24.99	26.51	26.39	27.42	n.s.
5-02-74	25.89			34.66	
5-14-74	20.72	20.74	21.37	24.64	.01
7-08-74	11.48	13.98	14.39	16.57	
8-29-74	5.19	6.48	7.77	9.13	.01
11-26-74	21.91	20.40	18.94	25.35	n.s.
4-02-75	12.98	13.31	15.16	18.20	.01
6-09-75	14.53	16.16	16.94	20.69	.01
8-04-75	13.38	13.81	15.55	20.61	.01
10-21-75	14.39	14.29	14.86	18.87	.01
2-12-76	16.86	17.65	19.85	21.77	.01
5-04-76	17.70	17.81	18.73	20.72	.01
7-28-76	15.31	17.20	17.70	19.39	.01
			Soil water holding capacity (%)		
5-02-74	41.71	43.92	45.82	50.28	.01
			Total bacterial count (no./g. x 10^6) on PMA agar		
7-07-72	146.4	140.5	266.6	303.7	.01
9-06-72	366.7	398.3	454.0	599.9	.05
2-20-73	88.8	137.0	196.7	282.9	.01
5-21-73	158.0	247.0	329.4	444.0	.01
8-01-73	50.9	63.9	90.3	148.8	.01
10-18-73	9.9	9.5	7.8	11.7	n.s.
2-20-74	62.5	53.8	73.2	94.9	n.s.
5-14-74	73.1	75.1	104.3	185.4	.01
8-29-74	215.3	198.4	232.1	371.1	.01
11-26-74	35.9	36.4	38.2	60.0	.01
4-02-75	27.8	31.6	37.4	55.8	.01
6-09-75	47.0	39.0	44.4	57.1	.01
8-04-75	92.1	71.7	98.2	138.1	.05
10-21-75	38.7	31.8	44.3	57.7	n.s.
2-12-76	100.9	90.1	107.7	119.2	n.s.
5-04-76	71.4	90.7	111.5	112.1	.05
7-28-76	89.5	117.8	130.2	92.4	.05

(continued)

TABLE 61. (continued)

Soil sampling dates	Sludge application rates 0	¼-Max	½-Max	Maximum	α-Level
Total bacterial count (no./g. x 10^5) on soil extract agar					
5-02-74	196.8			223.0	n.s.
8-29-74	502.3	636.3	512.3	547.5	n.s.
4-02-75	32.8	54.2	65	139.9	.01
6-09-75	160.1	136.0	184.1	270.1	.01
8-04-75	125.3	117.0	157.8	189.7	.01
10-21-75	9.9	10.3	27.4	50.3	.05
2-12-76	464.7	392.5	327.3	311.5	.01
5-04-76	66.6	90.3	171.0	195.3	.01
7-28-76	22.8	134.8	138.3	109.7	.01
Microbial spore count (no./g. x 10^4)					
7-07-72	57.9	69.2	46.1	45.6	.05
9-06-72	78.4	155.6	103.3	69.1	.01
2-20-73	133.9	185.8	142.4	99.7	.01
5-21-73	123.3	209.0	176.4	121.9	.01
8-01-73	76.9	128.0	108.3	69.4	n.s.
10-18-73	122.2	149.9	118.0	89.8	.01
2-20-74	197.9	206.8	151.7	142.2	n.s.
5-14-74	137.3	162.9	116.4	95.6	.05
8-29-74	57.5	75.1	95.2	77.6	.01
11-26-74	110.2	119.0	70.5	53.6	.01
4-02-75	111.9	142.2	84.8	82.9	.01
6-04-75	108.1	127.1	109.9	77.3	.01
8-04-75	77.3	94.2	63.9	53.6	.05
10-21-75	66.6	58.6	52.3	54.5	n.s.
2-12-76	85.8	103.6	72.8	64.6	.05
5-04-76	81.2	95.5	80.1	71.0	.05
7-28-76	76.5	96.1	72.9	50.3	.05
Fungi (no./g. x 10^4)					
5-02-74	20.82			17.06	n.s.
7-08-74	4.74	3.45	5.46	3.30	n.s.
8-29-74	1.18	0.96	1.50	2.38	0.01
4-02-75	18.48	17.43	21.88	35.15	0.01
6-09-75	21.88	22.86	24.95	29.41	n.s.
8-04-74	17.88	13.34	16.80	21.00	n.s.
10-21-75	17.42	18.28	20.66	21.34	n.s.
2-12-76	35.14	30.76	24.42	28.56	0.01
5-04-76	24.68	19.06	44.88	26.59	n.s.
7-28-76	19.69	20.61	26.08	19.46	n.s.

(continued)

TABLE 61. (continued)

Soil sampling dates	Sludge application rates				
	0	¼-Max	½-Max	Maximum	α-Level
			Actinomycetes (no./g. x 10^4)		
5-02-74	68.5			124.4	0.05
7-08-74	47.1	37.3	39.0	79.8	n.s.
8-29-74	25.3	41.0	45.5	154.1	0.01
4-02-75	10.0	12.7	9.9	7.6	n.s.
6-09-75	145.6	170.2	161.9	134.9	n.s.
8-04-75	175.0	193.5	313.8	391.1	0.01
10-21-75	116.4	150.9	182.4	212.5	0.05
2-12-76	47.9	77.6	218.7	372.4	0.01
5-04-76	105.1	118.2	136.6	163.4	n.s.
7-28-76	200.7	169.8	192.4	249.4	n.s.
			Azotobacter		
			% positive inoculations/plate		
5-02-74				3.50	
7-08-74	0.30	9.67	0.90	0.45	n.s.
8-29-74	82.00	56.37	55.35	26.20	.05
			No./g		
4-02-75	1956	1558	1414	943	.01
6-09-75	2539	1671	1914	1255	.05
8-04-75	1490	1473	1202	845	.01
10-21-75	1799	1432	1218	964	.05
2-12-76	1912	1585	1231	875	.01
5-04-76	2135	1636	1364	1000	.05
7-28-76	1601	1183	1218	936	.05
			Denitrifiers		
			% positive inoculations/plate		
5-02-74	55.50			91.50	.01
7-08-74	1.94	6.39	12.49	13.98	.05
8-29-74	32.28	14.88	20.84	37.95	n.s.
			Amylase activity (nM maltose/g./hr.)		
7-08-74	56.0	72.0	60.0	92.0	.01
4-02-75	184.4	168.1	180.2	243.1	.05
6-09-75	43.6	42.2	47.5	55.0	.01
8-04-75	232.3	279.2	280.2	383.8	.01
10-21-75	187.3	202.1	236.3	261.5	.01
2-12-76	291.0	279.8	272.9	333.9	n.s.
5-04-76	327.1	290.2	311.8	288.6	n.s.
7-28-76	183.6	268.4	295.5	285.4	n.s.

(continued)

TABLE 61. (continued)

Soil sampling dates	Sludge application rates 0	¼-Max	½-Max	Maximum	α-Level
Catalase activity (μM H_2O_2/g./min.)					
6-09-75	11.47	13.18	16.23	22.07	.01
8-04-75	11.81	14.29	15.50	19.66	.01
10-21-75	13.58	15.87	16.12	19.61	.01
2-12-76	18.32	19.59	19.84	22.53	.01
5-04-76	13.50	13.73	18.10	20.58	.01
7-28-76	11.23	12.38	14.93	13.56	n.s.
Cellulase activity (nM glucose/g./hr.)					
5-02-74	40.0			29.0	.01
7-08-74	27.0	31.0	30.0	35.0	n.s.
8-29-74	7.0	5.0	4.0	6.0	n.s.
4-02-75	27.6	23.3	24.0	40.0	n.s.
6-09-75	15.3	14.2	14.8	16.7	n.s.
8-04-75	85.3	88.8	98.4	104.8	n.s.
10-21-75	151.5	152.9	158.9	170.7	n.s.
2-12-76	103.9	101.1	102.9	114.5	n.s.
5-04-76	26.4	23.7	39.3	44.4	.01
7-28-76	44.5	43.0	49.4	44.5	n.s.
Dehydrogenase activity (μg TPF[a]/24 h/g)					
5-02-74	638			940	n.s.
7-08-74	4338	1863	1748	1746	.01
8-29-74	355	212	318	1629	.05
Invertase activity (mg. glucose/g. soil) Gravimetric Method					
9-06-72	9.86	8.75	8.09	7.70	.01
2-20-73	12.97	10.23	8.92	8.49	.05
5-21-73	17.84	16.30	17.44	15.06	n.s.
10-18-73	14.98	16.66	13.91	14.60	n.s.
2-20-74	18.82	18.08	17.14	16.73	n.s.
5-14-74	16.72	12.89	13.42	17.67	n.s.

(continued)

TABLE 61. (continued)

Soil sampling dates	Sludge application rates 0	 ¼-Max	 ½-Max	 Maximum	α-Level
	Invertase activity (nM glucose/g./hr.)				
	Colorimetric Method				
4-02-75	7460	7476	6157	6446	n.s.
6-09-75	7643	4139	6085	10554	.05
8-04-75	4730	3800	5569	8438	.01
10-21-75	1525	1438	1738	2077	n.s.
2-12-76	2555	2285	2211	2478	n.s.
5-04-76	1336	1388	2296	2557	.01
7-28-76	1915	2590	2708	2562	n.s.
	Protease activity (mg. amino-N/100g.)				
5-02-74	394.0			705.0	.01
7-08-74	383.0	446.0	524.0	609.0	.01
8-29-74	110.0	185.0	229.0	273.0	.01
6-09-75	268.3	365.3	421.5	557.5	.01
8-04-75	242.0	325.7	357.4	445.8	.01
10-21-75	171.6	206.9	222.5	261.3	.01
2-12-76	257.4	284.5	288.9	371.1	.01
5-04-76	139.6	152.6	197.9	205.8	.01
7-28-76	86.2	112.9	155.2	150.2	.05
	Urease Activity (mg NH_4-N/100g)				
5-02-74	145.0			277.8	n.s.
7-08-74	81.6	106.8	90.0	86.2	n.s.
8-29-74	126.0	171.9	159.8	187.2	n.s.
	Xylanase activity (nM glucose/g./hr.)				
4-02-75	59.63	44.21	53.47	69.24	n.s.
6-09-75	20.53	21.37	21.79	24.73	n.s.
8-04-75	171.10	141.90	187.60	240.20	.01
10-21-75	77.40	81.30	108.30	116.60	n.s.
2-12-76	101.42	91.98	100.82	119.31	n.s.
5-04-76	77.48	75.70	129.30	138.10	.01
7-28-76	103.30	93.99	113.02	122.20	n.s.

(continued)

TABLE 61. (continued)

Soil sampling dates	Sludge application rates 0	¼-Max	½-Max	Maximum	α-Level
	Soil microbial respiration				
	mg CO_2/72h/10g				
5-02-74	0.92			1.44	.05
7-08-74	0.61	1.26	1.20	1.46	.01
7-08-74 b/	2.27	2.90	3.16	2.77	n.s.
8-29-74	0.57	0.84	0.99	1.12	.01

*The plots were identified as NW800 series. All values based on dry weight of soil.

n.s. Not significantly different.

a/ TPF = 2,3,5-Triphenyl formazan

b/ Enriched with 2 mg KNO_3 and 100 mg glucose per 10g of soil.

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TABLE 62. MOISTURE CONTENTS AND BIOLOGICAL ACTIVITY IN SOIL FROM LYSIMETER PLOTS OF BLOUNT SILT LOAM, ELLIOTT SILT LOAM AND PLAINFIELD LOAMY SAND.*

Date	Soil type	Sludge application rates			
		0	¼-Max	½-Max	Maximum
		---------------% Moisture---------------			
12-07-72	Blount	18.82	18.42	20.05	21.40
	Elliott	20.40	20.57	22.47	22.80
	Plainfield	8.71	7.80	9.34	10.37
5-21-73	Blount	14.13	14.93	16.36	18.58
	Elliott	16.96	16.04	17.58	19.94
	Plainfield	4.58	5.84	5.51	7.36
8-01-73	Blount	11.34	9.83	10.44	12.94
	Elliott	11.49	10.24	11.06	13.23
	Plainfield	2.12	1.91	1.88	3.39
10-18-73	Blount	15.76	16.00	17.14	20.12
	Elliott	17.47	17.21	18.00	19.36
	Plainfield	5.36	6.25	6.02	9.62
2-20-74	Blount	19.43	20.28	22.22	24.48
	Elliott	22.85	20.65	23.62	22.50
	Plainfield	7.51	8.73	10.37	11.86
6-03-74	Blount	13.93			19.63
	Elliott	15.57			19.54
	Plainfield	4.66			10.15
All Combined	Blount	15.57	15.89	17.24	19.52
	Elliott	17.46	16.94	18.55	19.56
	Plainfield	5.49	6.10	6.62	8.79
		------Total bacteria (No./g X 10^6)------			
12-07-72	Blount	99.4	122.4	163.4	191.1
	Elliott	119.9	168.8	223.1	275.5
	Plainfield	62.8	65.0	127.1	130.1
5-21-73	Blount	12.7	15.8	20.4	37.3
	Elliott	14.9	22.4	24.8	46.1
	Plainfield	13.2	12.2	16.2	29.0
10-18-73	Blount	26.9	26.7	25.8	37.0
	Elliott	40.0	49.6	38.6	68.2
	Plainfield	18.4	20.8	28.7	62.3
2-20-74	Blount	79.7	90.5	79.1	127.4
	Elliott	81.3	82.0	83.2	116.4
	Plainfield	49.4	76.7	46.5	77.2

(continued)

TABLE 62. (continued)

Date	Soil type	Sludge application rates 0	¼-Max	½-Max	Maximum
		-----------Total bacteria (No./g X 10^6)-------			
6-03-74	Blount	15.7			41.6
	Elliott	41.7			55.9
	Plainfield	9.5			30.3
All Combined	Blount	46.9	63.9	72.2	86.9
	Elliott	59.5	80.7	92.4	112.4
	Plainfield	30.7	43.7	54.6	68.2
		--Microbial spore counts (No./g X 10^4)--			
12-07-72	Blount	89.7	172.6	234.7	184.7
	Elliott	213.9	162.9	303.0	117.8
	Plainfield	27.8	47.3	17.8	16.6
5-21-73	Blount	61.6	84.2	110.8	84.8
	Elliott	147.5	200.9	116.4	157.1
	Plainfield	27.0	31.3	19.1	31.8
10-18-73	Blount	224.2	162.3	133.7	137.8
	Elliott	252.7	226.0	198.0	174.9
	Plainfield	41.2	66.2	78.8	80.2
2-20-74	Blount	165.6	230.1	277.7	369.1
	Elliott	212.6	262.1	364.3	188.8
	Plainfield	43.5	69.8	44.9	34.0
6-03-74	Blount	115.8			99.0
	Elliott	318.0			185.1
	Plainfield	91.0			77.2
All Combined	Blount	131.4	152.3	189.2	173.5
	Elliott	228.9	213.0	245.4	164.7
	Plainfield	46.1	53.6	40.1	48.0
		----Invertase activity (mg glucose/g)--- -----------Gravimetric method-----------			
12-07-72	Blount	6.93	7.21	7.40	8.19
	Elliott	11.84	11.19	11.78	13.91
	Plainfield	7.78	8.06	8.55	5.91
5-21-73	Blount	10.19	10.88	12.47	15.60
	Elliott	15.07	14.43	15.47	17.39
	Plainfield	9.06	7.48	7.02	8.83
10-18-73	Blount	10.08	11.27	13.44	14.72
	Elliott	14.98	15.69	15.80	17.58
	Plainfield	7.46	7.91	7.22	10.73

(continued)

TABLE 62. (continued)

Date	Soil type	Sludge application rates			
		0	¼-Max	½-Max	Maximum
		----Invertase activity (mg glucose/g)-------			
		-----------Gravimetric method---------------			
2-20-74	Blount	12.36	11.24	14.04	16.76
	Elliott	15.36	14.12	15.06	16.00
	Plainfield	9.54	8.99	8.77	7.95
6-03-74	Blount	11.76			18.61
	Elliott	14.39			19.51
	Plainfield	7.35			10.92
All Combined	Blount	10.27	10.15	11.84	14.78
	Elliott	14.33	13.86	14.53	16.88
	Plainfield	8.24	8.11	7.89	8.87

*Values are based on dry weight of soil.

TABLE 63. MOISTURE CONTENTS AND BIOLOGICAL ACTIVITY IN THE SURFACE (0-15 cm) OF CONTINUOUS CORN PLOTS ON STRIP-MINED LANDS.*

Date	Sludge application rates				
	0	¼-Max	½-Max	Maximum	α-Level
	----------------------Moisture %----------------------				
9-03-74	10.09	11.07	12.20	12.52	.01
10-31-75	11.68	12.92	13.05	12.02	n.s.
2-13-76	10.91	10.01	10.71	10.58	n.s.
5-24-76	5.54	7.25	6.83	6.49	n.s.
8-04-76	11.92	12.41	12.56	12.49	n.s.
	----Total bacterial count (no./g. x 10^5) on PMA agar----				
9-03-74	74.31	138.46	135.10	129.30	n.s.
10-31-75	67.43	82.57	98.04	132.98	.01
2-13-76	90.31	111.37	129.96	157.83	.05
5-24-76	92.37	95.77	57.34	102.94	n.s.
8-04-76	90.79	104.00	175.60	148.20	.05
	-Total bacterial count (no./g. x 10^4) on soil extract agar-				
10-31-75	91.75	149.58	191.86	163.39	.05
2-13-76	467.60	473.10	376.30	529.90	n.s.
5-24-76	71.93	88.22	84.96	122.02	.01
8-04-76	89.97	136.71	179.13	207.40	.05
	----------Microbial spore count (no./g. x 10^3)----------				
9-03-74	280.30	369.70	402.80	416.80	.05
10-31-75	65.73	60.03	49.45	48.89	n.s.
2-13-75	42.62	92.14	79.64	59.76	.05
5-24-76	125.36	130.04	135.56	115.49	n.s.
8-04-76	70.56	59.02	65.99	89.69	n.s.
	-----------------Fungi (no./g. x 10^3)-----------------				
10-31-75	41.95	44.61	45.81	59.17	n.s.
2-13-76	44.70	38.18	37.82	66.22	.05
5-24-76	36.71	36.84	35.58	39.11	n.s.
8-04-76	29.37	23.41	25.43	37.44	n.s.
	--------------Actinomycetes (no./g. x 10^4)--------------				
10-31-75	84.43	86.81	97.24	99.56	n.s.
2-13-76	117.27	146.80	161.31	191.53	n.s.
5-24-76	101.72	134.67	138.88	144.31	n.s.
8-04-76	161.80	168.50	176.70	177.40	n.s.
	-----------------Azotobacter (no./g.)-----------------				
10-31-75	164.5	372.1	245.3	164.8	n.s.
2-13-76	177.4	204.3	191.1	220.6	n.s.
5-24-76	865.3	670.9	907.5	557.7	n.s.
8-04-76	608.0	440.5	742.8	653.3	n.s.

(continued)

TABLE 63. (continued)

Date	Sludge application rates				
	0	¼-Max	½-Max	Maximum	α-Level
---------Amylase activity (nM maltose/g./hr.)-----------					
10-31-75	187.3	202.1	236.3	261.5	.01
2-13-76	136.5	158.3	168.5	196.5	.01
5-24-76	171.6	179.0	219.6	255.0	.01
8-04-76	177.2	187.6	203.2	221.0	n.s.
-----------Catalase activity (μM H_2O_2/g./min.)----------					
10-31-75	7.10	8.42	8.92	9.52	.05
2-13-76	6.43	9.38	10.04	13.01	.01
5-24-76	3.34	5.12	5.29	5.79	n.s.
8-04-76	7.48	9.02	9.40	8.34	n.s.
---------Cellulase activity (nM glucose/g./hr.)---------					
10-31-75	4.33	4.42	5.10	6.19	n.s.
2-13-76	5.29	5.00	7.19	9.13	.05
5-24-76	7.72	8.68	9.54	12.74	n.s.
8-04-76	10.63	10.29	11.50	15.01	n.s.
-Invertase activity colorimetric method (nM glucose/g./hr.)-					
10-31-75	1524.0	1438.0	1738.0	2077.0	n.s.
2-13-76	753.7	860.5	999.3	1236.5	.05
5-24-76	614.8	591.2	569.9	733.1	n.s.
8-04-76	654.3	881.8	1014.0	1129.0	.01
----------Protease activity (mg. amino-N/100g.)---------					
10-31-75	100.9	114.4	133.1	131.8	.01
2-13-76	43.0	51.1	69.4	80.3	.05
5-24-76	21.8	32.7	34.5	41.9	.01
8-04-76	14.5	34.0	60.6	56.8	.05
---------------Xylanase (nM glucose/g./hr.)-------------					
10-31-75	77.41	81.34	108.30	116.60	n.s.
2-13-76	17.42	19.45	27.16	34.44	.05
5-24-76	12.38	22.92	22.42	31.30	.01
8-04-76	30.04	38.15	42.65	44.65	n.s.

*All values are based on dry weight of spoil materials.
n.s. Not significantly different.

primarily during periods of increased nutrient availability due to the addition of organic matter and/or moisture to the soil. The results of aerobic spore count in Blount silt loam from long-term continuous corn plots (Table 61) suggest a significant decrease in numbers of spores due to increasing sludge application. This change was apparently due to a decrease in the overall sporolation rate in response to the increased availability of nutrients and moisture derived from sludge. The possibility that the change is due to a decrease in the number of spore-forming organisms rather than a decrease in overall sporolation rate is unlikely in view of the observed increase in total count. Results from the lysimeter plots (Table 62) where accumulative sludge application rates were slightly less and where drainage was better, indicated a more complex situation. In the long-term plots (Table 61), the highest counts were obtained from the lowest level of sludge treatment (¼-maximum) with the untreated plots yielding values slightly lower. The lysimeter plots, (Table 62) however, had the highest counts at the ½-maximum level of treatment with an apparent increase from untreated to the ½ level. During early sampling of strip-mine spoil banks (Table 63) spore-formers increased with higher sludge loading rates. Apparently, sludge treatments increased sporolation rates up to a point where organisms adapt to the new environmental conditions and then sporolation rate decreased as more and more organic matter accumulated in soils. A comparison of aerobic spore count obtained from the different soil types (Table 62) showed results similar to those found for total count and likewise in accordance with the differences in organic matter and moisture retention of the three soil types. Elliott silt loam soil had the highest spore count because of a higher population of spore-formers and not because of a higher sporolation rate. Plainfield loamy sand had the lowest spore count of the three soil types studied.

Fungi and Actinomycete Populations--

Numbers of fungi and actinomycetes found in samples from Blount silt loam and strip-mine spoil plots are shown in Tables 61 and 63, respectively. Some of the treatment means indicate an increase in fungi but the results are generally inconclusive and the treatment effect is seldom statistically significant. The results for strip-mine spoil plots were similar to those for Blount silt loam, but were lower in absolute value. Overall treatment means for both sets of plots indicated a considerable increase in actinomycetes with increasing sludge treatment. Numbers of actinomycetes in samples from the strip-mine spoil plots were consistently increased with sludge treatment, but the differences were not statistically significant. Where numbers of actinomycetes in Blount silt loam soil were significantly increased the data showed considerable variation in the magnitude of increase to sludge applications from one sampling period to the next. With respect to soil and spoil materials, actinomycetes populations were considerably less in the latter. Regardless of crop rooting media, numbers of actinomycetes were always higher than fungi. It appears that sludge applications caused a short-lived increase in fungi as compared to actinomycetes. Alexander (1961) points out that populations of actinomycetes remain high during soil drying as compared to bacteria and fungi.

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Azotobacter and Denitrifier Populations--

No significant differences between treatments were observed in results from *Azotobacter* assays in samples collected from strip-mine spoil plots. The significant decrease in populations of *Azotobacter* due to sludge application as generally observed in samples from Blount silt loam plots, may have been caused by high concentrations of P. Phosphate concentrations above 2000 mg/kg in soils have been found to depress proliferation of this genus (Brown 1962). A low population of *Azotobacter* may sometimes be due to either inadequate or excessive soil contents of B (Gerretsen and DeHoop 1954), Mg (Jensen 1954), Cu (Mulder 1938), or some other elements such as Mo (Becking 1962) or V (Alexander 1961). From results of other studies, concentrations of B and Mo were probably too low in digested sludge to have adversely affected these soil microorganisms. Sufficient information in not presently available to speculate about the effects of V concentration levels on *Azotobacter* populations in sludge-amended soils. If the decrease in *Azotobacter* populations with sludge loading rates can be attributed to difference in concentration levels of trace elements, Cu is the most likely candidate. The Cu supplied as a constituent of sludge was probably highly chelated and, thus, considerably more available than similar quantities in normal soils. The amount of total Cu in soils was higher in Blount silt loam than in the strip-mine spoil plots which were established at a much later date.

The significant increase in percent of denitrifying bacteria with increasing sludge treatment may be interpreted by reference to the losses of N when nitrate-N was added to digested sludge and soil and digested sludge mixtures (Table 61). It was reported that the rate of denitrification was higher in sludge alone than in sludge-soil mixtures (Hinesly et al. 1974). Losses of nitrate-N may have been caused mainly by anaerobic conditions in sludge alone, but it is also possible that digested sludge contains a higher percentage of bacterial species capable of performing denitrification processes than are normally present in soils. However, it may also be speculated that the rate of denitrification under near optimum conditions of aeration, moisture content, temperature, etc., will be higher in soils where long-term applications of digested sludge has led to better soil aggregation than was originally present in untreated soil (Epstein 1973). From the results of soil respiration studies, Greenwood (1961) showed that water-saturated soil crumbs having radii greater than 3 mm have no oxygen at their centers. He stated that since crumbs of this size are present in most soils, localized pockets of anaerobic conditions are widespread and provide an explanation for the universal occurrence of strict anaerobes. In this connection, unpublished results from some of our other studies show that the percentage of water stable aggregates >0.25 mm in diameter increase positively with an increase in digested sludge application rates. In samples from control and maximum-sludge-treated plots, the percentage of aggregates >0.25 mm in diameter were 9.7 and 22.8 percent, respectively. This suggests that the percent of crumbs >3 mm in radius may have also been greater in sludge amended plots, explaining the increased population of denitrifying bacteria with greater sludge loading rates during the early part of the growing season when soil moisture conditions were more favorable. The lack of significant differences in percent of denitrifiers between treated and untreated soil samples on August 29, may be attributed to the confounded effects of low soil moisture contents and abnormally high soil contents of accumulated NH_4-N in sludge-treated plots, both of which would tend to inhibit the growth of denitrifying organisms.

Enzyme Activities--

Amylase activity tended to be significantly higher in both Blount silt loam and strip-mine spoil, annually amended with high sludge loading rates. Increases in amylolytic activity were probably the result of sludge applications rather than to vegetative contributions because some of the significant increases in amylase activity were found during winter sampling periods and in the spring before planting corn. Catalase activity was increased by sludge applications in both Blount silt loam and strip-mine spoil materials. Regardless of treatment, catalase activity was higher in Blount silt loam than strip-mine spoil materials. Cellulase activity was seldom increased as a result of sludge application in samples from either Blount silt loam or strip-mine spoil plots. As discussed earlier, amounts of polysaccharides and cellulose concentrations were considerably higher in maximum-sludge-treated than in untreated Blount silt loam plots (Table 58). Therefore, the lack of differences in cellulolytic activity was not caused by lack of substrate but more likely due to the fact that microorganisms did not need to excrete cellulolytic enzymes. Generally the number of bacteria producing cellulolytic enzymes in soils is a small percent of the total microflora (Hankin et. al., 1974). Cellulase activity was considerably lower in strip-mine spoil materials than in Blount silt loam soil. Biological activity of soil is subject to frequent variations as a result of changes in temperature, humidity, light conditions, pH, and redox potential, as well as qualitative and quantitative changes in availability of nutrients. Therefore, significant variations of dehydrogenase activity encountered in this study probably reflect rapidly changing environmental conditions (Table 61). At any rate, the number of determinations of dehydrogenase activity were too few to relate rates to sludge treatments. Invertase activity, as measured by the colorimetric procedure, was usually higher in samples of soil or spoil material treated with higher sludge loading rates. The work of Esterman (1961) and Nowak (1964) stressed the dominating role of plants in secreting invertase. Ross (1966) found that climatic conditions and vegetation had greater effects on activities of invertase and amylase than mineral composition of soil or parent material. Thus, the significant differences in the invertase activity in sludge-treated and untreated plots was as expected in Blount silt loam soil. Because corn yields were frequently increased by higher rates of sludge it was expected that the secretion of invertase by corn roots would result in higher levels of activity even though sludge caused no direct effect on invertase-producing microflora. On the other hand, corn yields were not markedly affected by sludge treatments as compared to those from control plots on strip-mine spoil materials. Thus, higher invertase activity in in strip-mine material amended with sludge was not explained by higher corn yields of grain or stover. Activity of protease increased significantly with sludge applications on both Blount silt loam and strip-mined lands. Since Hoffman and Teicher (1957) found a positive correlation between protease activity and soil organic matter contents, the increased activity with sludge applications may have been predictable. Several researchers have reported the existence of active, stable enzyme-humus complexes in soil (Chalvignac and Mayandon 1971). Complexed enzymes are less active than free enzymes (Rowell et al., 1973) but apparently activity of enzymes is preserved in the soil for much longer periods of time by complexation. Results from experiments performed by Ladd and Butler (1970) show that the increased activity of protease in soils may be due to the displacement of enzymes from the complex with humus by metallic ions like Mg^{2+} or Na^{+}. The proportion of the increased protease activity with increasingly greater sludge application rates caused by enzyme displacement with ions of soluble salt constituents in sludge has not yet been determined. Xylanase activity was increased by sludge applications of both Blount silt loam and strip-mined spoil materials amended with sludge. Like the activities of several other enzymes, xylanase activity was always higher in soil than in strip-mine spoil.

Amounts of CO_2 evolved during incubation of soil samples from experimental plots were always positively correlated with the amount of sludge applied. These results are in accordance with the results of previous studies performed in our laboratory (Hinesly et al., 1974) and with increased activity of dehydrogenase with increasingly greater amounts of applied sludge, as found in samples collected on August 29. Additional soil respiration experiments conducted on samples collected on July 8 revealed that even an approximate balancing of the amounts of N and easily available carbohydrates in check soils erases significant differences in amounts of CO_2 evolved between treated and untreated plots (July 8b, Table 61). This also suggests that the number of active microorganisms in untreated soils may be similar or can be rapidly increased to populations equivalent to those in sludge amended soils by additions of energy and nutrient substances. Total counts of bacteria performed on soil extracts as previously discussed seemed to confirm this observation. Apparently the 1 percent, by weight, of glucose added as a carbon source to the July 8b samples is more readily available than the carbon in sludge remaining in treated plots. Different substrates give different rates of CO_2 evolution (Lees and Porteous 1950), and results from studies employing glucose as a substrate are not directly comparable to those obtained by the use of a complex material like sludge. It can be seen from the results reported in Table 58 that the polysaccharides content in soil samples from maximum-sludge-treated plots is almost 1.5 times that found in samples from control plots, but the carbon in these compounds is not so readily available as in glucose. Even if there are some drawbacks of Cornfield's method of CO_2 measurement (Douglas and Bremner 1971) our results are comparable to those reported by Miller (1974).

Except for Azotobacter, no clear-cut evidence was found that microbial populations and their activities were restricted by sludge applications. The most popular explanation for a decrease of Azotobacter populations with higher sludge application rates is that they were unable to compete successfully with other organisms in the presence of abundant nutrient supplies.

INFLUENCE OF MUNICIPAL SEWAGE SLUDGE ON MINERALIZATION OF PLANT RESIDUES AND CHANGES IN MICROBIAL POPULATIONS

General Description

Heavy metals have been shown to affect some microbiological processes in the soil. Premi and Cornfield (1969) found that the additions of Cu, Mg, Zn, and Cr to soil usually inhibited ammonification and nitrification. These effects varied considerably depending on the level and kind of cation, oxygen levels, and pH of the environment. In later research, Premi (1970) found that 5 and 10 mg/kg Zn and Cu adsorbed on purified peat and sewage, and 100 and 1000 mg/kg added as sulfates (Permi and Cornfield 1970), enhanced mineralization of organic-N, although nitrification was inhibited at higher levels of these metals. On the other hand Cd and Pb stimulated nitrification in mull soil according to Tyler et al. (1974). Tyler (1974) also found decreased activity of hydrolytic enzymes such as urease and acid phosphatase in spruce litter polluted with Cu and Zn. Rühling and Tyler (1973) showed that the general decomposition rate of spruce needle litter was reduced when the litter contained relatively low concentrations of Cu, Zn, Cd, Ni, and Pb. Miller (1973) found large increases of bacteria, fungi, and actinomycetes in soils as a result of sludge applications.

The purpose of this study was to determine the direct influence of metals, added as a constituent of sludge, on the mineralization of plant residues as compared to the indirect influence of metals accumulated by plants. Another objective was to determine the dynamics of enzymatic processes occuring during mineralization of plant residues, along with population changes of specific groups of microorganisms. Particular attention was given to fungi which were known to be an active group in the degradation of plant residues (Charpentier 1968).

The following materials were used in experiments: (1) Heated, anaerobically digested sludge was obtained from the Calumet, and West Southwest treatment plants of the Metropolitan Sanitary District of Greater Chicago. The sludge was dried in a sand bath heated by a steam (80°C). (2) Plant materials were ground corn stalks harvested from two lysimeter plots of Plainfield loamy sand, one of which was annually treated with approximately 50 mt/ha of sludge each year over a 7-year period (treated residue), and the other amended only with inorganic fertilizers (control residue). (3) Pure Ottawa (quartz) sand.

Two hundred gram samples of sand, sludge and plant material were incubated in 0.5 1 bottles in the following combinations:

1. CR (control residue): sand + 2% (w/w) plant material from a Plainfield loamy sand plot which had received inorganic fertilizer but no sludge.
2. TR (treated residue): sand + 2% plant material from Plainfield loamy sand plot which had received the maximum sludge treatment.

3. CRS: sand + 2% (w/w) plant materials from the control Plainfield loamy sand plot + 2% (w/w) dried sludge (an amount of sludge approximating the annual amount applied to the soil).
4. S: sand + 2% dried sludge.

In order to enrich the nitrogen content as required for mineralization the following mineral salts were added to the first two combinations: NH_4NO_3(0.3 g), KH_2PO_4(0.1 g), and NaCl(0.04 g). The C:N ratio at the beginning of the experiment was 15:1 for CR, 11:1 for TR, 22:1 for CRS, and 9:1 for S. In the CRS combination the C:N ratio was the highest, but the amounts of N were sufficient to sustain mineralization processes at rates equivalent to other combinations. This was assumed to be true on the basis of Miller's (1973) findings and confirmed by results reported here showing that sludge organic-C was involved in mineralization processes to only a small extent. All combinations were inoculated with 0.5% of Plainfield loamy sand from the control plots. Deionized water was added to all combinations to adjust the moisture content to 60% of saturation. The samples were incubated at room temperature (22-24°C) during a 24-week period. Chemical and enzymatic analyses were carried out after 1, 2, 4, 8, 16, and 24 weeks of incubation. To obtain an average sample, the three replicated 200g samples were combined for the several analyses at the end of each of the above incubation periods. All chemical and enzymatical analyses were performed in two to four replications. Organic-C was determined by the Walkley-Black method (Allison 1965). The total amounts of N were determined by the Kjeldahl method (Bremner 1965) and NH_4-N and NO_3-N concentrations were determined by Bremner's (1965) method. The amounts of organic-N were calculated by subtracting the NH_4-N from the total N. A Corning Model 12 pH-meter was used to determine sample reaction (pH). The amounts of metals in sludge and plant material were determined as described in Section I of this report.

Cellulase was assayed using the Pancholy and Rice (1973) method with carboxylmethylcellulose as a substrate. Samples with the substrate were incubated at 30°C for 48 hours at pH 5.5. The results were expressed as nmoles of glucose/hr/gram of the mixture. The activities of peroxidase and exophenolo-oxidase (laccase) were determined by the colorimetric method of Trojanowski et al. (1971) using p-phenylenediamine as a substrate. The extracts for determination of these enzymes were prepared by shaking 50 g of sample with 50 ml of buffer and centrifuging. Phosphate buffers at pH 7 for peroxidase and pH 5.2 for laccase were used for preparation of extracts. The activity of peroxidase in units specific for this method was calculated from the equation:

$$\frac{\Delta E}{v \times t \times d}$$

where ΔE was the increase in absorption measured at 550 nm, v, the volume of enzyme solution (ml); t, the time of incubation (min); and d, the protein content in mg/ml of the extract. Protein content was determined by the procedure of Lowry et al. (1951). The activity of laccase was calculated from the equation:

$$\frac{E \times 10^6}{f \times t}$$

where f is the coefficient (for Bandrowski base = 1200); E, the absorption measured at 550 nm; and t, the time in minutes.

The total counts of bacteria, actinomycetes and fungi were performed by the agar plate method. Soil extract agar, according to Lochhead (1940), was used for bacteria and actinomycetes. The soil used for the inoculation of samples was also used for the preparation of soil extract. Rosebengal streptomycin agar, according to Martin (1950), was used to obtain the total count of fungi. Plates in 3 to 5 replications for each sample were incubated from 7 to 10 days.

The medium used for cellulolytic fungi consisted of the following: 2.0 g NH_4NO_3, 1.0 g KNO_3, 1.0 g K_2HPO_4, 0.5 g KCL, 0.5 g $MgSO_4$, 0.01 g $FeSO_4$, traces of $CaSO_4$ and NaCl, and 20 g agar in 1000 ml of water. Sterilized Whatman filter paper placed on the surface of solid medium in plates provided the source of cellulose. For the determination of fungi able to grow on lignin, a modified medium according to Day et al. (1949) was used. Modification of the medium consisted of the addition of 0.01 g of p-phenylenediamine and 1.0 g of Kraft lignin, (Indulin AT Westvaco. Polychemical Div., Charleston, West Virginia). Both media were inoculated with 90 to 120 sand grains from each sample. Incubation was carried out for 14 days. The results were expressed as the percent of positive grains of total inoculated per plate.

The dilution tube count technique (Harrigan and McCance 1966) was used for determining the number of cellulolytic bacteria. The liquid medium for cellulolytic bacteria consisted of the following: 1.0 g KNO_3, 0.5 g K_2HPO_4, 0.2 g $MgSO_4$, 0.2 g NaCl, 5.0 g $CaCo_3$, and traces of Mn, Fe, and Mo salts per 1000 ml of water. The sources of cellulose was Whatman filter paper. Strips of filter paper were placed into each tube with liquid medium, which were then inoculated with 1.0 ml of successive 10-fold soil dilutions in three replications. Incubation period was 20 days. Growing bacteria were visible as colored slime at the liquid-atmosphere interface on strips of filter paper. Bacterial numbers were calculated from probability tables (Rodina 1968).

Inoculated media were incubated at 25°C. Results were expressed as the number of cells per 1 g oven-dry soil. Microscopic identification of fungi was carried out directly on plates. Colonies of fungi not readily identified were transferred to potato-dextrose agar (Johnson et al., 1960) and examined later.

Results and Discussion

Mineralization of Corn Residues and Activity of Enzymes--

Losses of organic-C were the reflection of the total activity of microorganisms participating in the mineralization of plant residue and sludge. The most rapid degradation took place in the first 4 weeks of incubation as shown in Fig. 105. The greatest loss of C (784mg/100g mixture) was found at the end of 24 weeks of incubation in the combination with control residue and sludge (CRS). Lesser losses of C were found for other combinations. Carbon losses amounted to 687 mg/100 g for control residue (CR), 518 mg/100 g for treated residue (TR), and 55 mg/100 g for sludge alone (S). Organic-C contained in digested sludge underwent slow mineralization because scarcely 12% was mineralized in the combination with sludge alone (S). In the combination with sludge and control residue (CRS) the organic-C in specific components was mineralized at a rate similar to combinations in which sludge and plants were incubated separately. This appears to be true because the sum of the amounts of mineralized C in the CR and S combinations were similar to amounts found in the CRS combination. However, plant residues may have permitted co-metabolism of sludge components that would not have been degraded, otherwise.

Cellulose makes up about 46.5% and lignin about 19.5% of the dry matter of cell walls in mature corn stalks (Siegel 1968) and thus enzymes hydrolyzing these compounds were studied. In all combinations containing plant material (CR, TR, CRS) maximum activity of cellulase occurred after only one week of incubation (Fig. 106). This activity was attributed to fungi which are distinguishable from bacteria and actinomycetes by their ability to produce considerable amounts of exocellulases (Charpentier 1968). Enzyme activity was greatest in the combination containing plant material from treated plots (TR). With sludge alone (S), enzyme activity was minimal during the whole incubation period. For the combination containing sludge and control residue (CRS), cellulase activity decreased gradually during the incubation. The increases of cellulase activity after incubating control (CR) and treated residues (TR) combinations may have been caused by repeated synthesis of cellulases, or by release of enzymes after lysis of cells. The latter suggestion seems more convincing as the reason for the increases in activity after 8 weeks of incubation because the low rate of mineralization found in this period would indicate that available cellulose substrate (the inducer for cellulase synthesis) was exhausted. In the combination containing treated residue (TR), the activity of cellulase was greater than the activity in the combination with control residue (CR). The explanation of this fact may lie in the greater numbers of cellulolytic fungi found in the TR combination after 2 weeks of incubation, although the composition of genera in both samples was similar.

No correlation was found between the rate of mineralization and cellulase activity since the greatest loss of organic-C occurred in samples with control residue (CR and CRS), whereas cellulase activity in both cases was lower than in combinations with treated residues (TR). Microbiological analyses indicated that cellulolytic bacteria were present and their contribution to mineralization of cellulose in both combinations with control residue (CR and CRS) was probably one of the reasons for the lack of correlation.

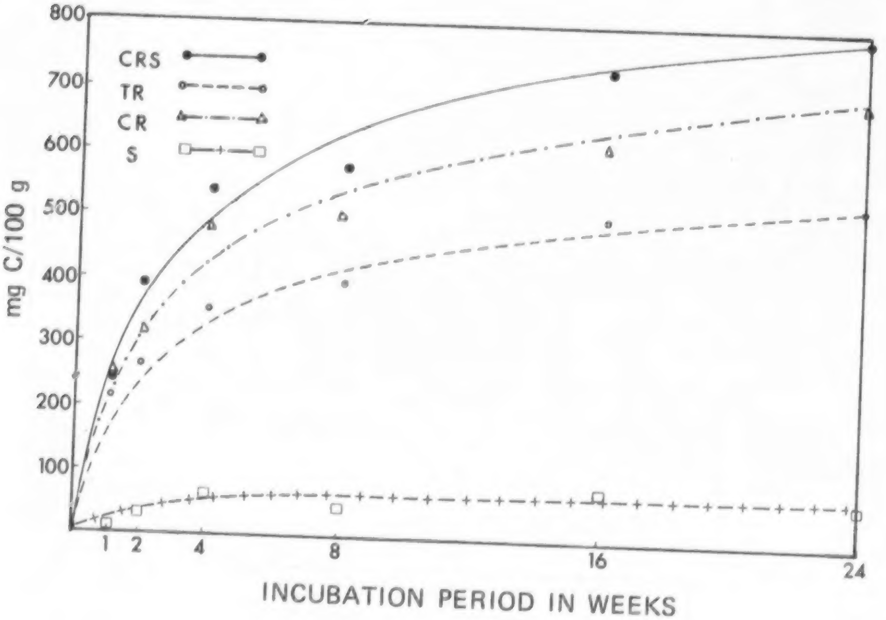

Figure 105. Losses of organic carbon from incubated samples of sludge corn residues, and corn residues plus sludge after 1, 2, 4, 8, 16, and 24 weeks. Comparing control residues (CR) with treated residues (TR) losses were significantly different at the 0.05 probability level after 2 weeks of incubation and at the 0.01 probability level for all succeeding incubation periods. Differences between control residue (CR) and control residue plus sludge (CRS) were significant at the 0.05 probability level for samples incubated for 2 and 4 weeks and at the 0.01 probability level for samples incubated for 8, 16, and 24 weeks.

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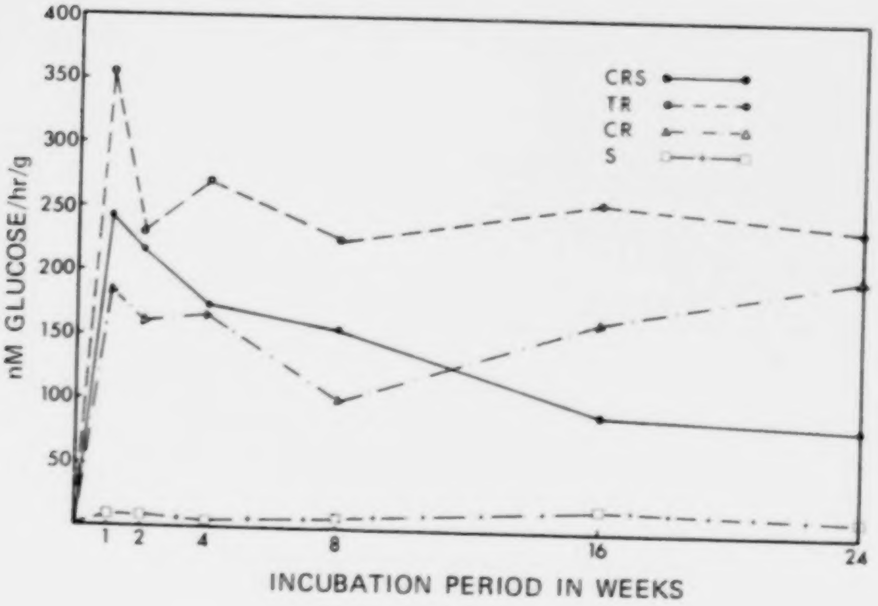

Figure 106. Cellulase activity in samples of sludge, corn residues and sludge plus corn residues. Comparing control residues (CR) with treated residues (TR) activity was significantly different at the 0.01 probability level after 1, 2, 4, 8, and 16 weeks of incubation and at the 0.05 probability level for the samples incubated for 24 weeks. Differences between control residues (CR) and control residues plus sludge(CRS) were significant at the 0.01 probability level for samples incubated for 2, 16, and 24 weeks, and at 0.05 probability level for samples incubated for 8 weeks.

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100 - 498

Peroxidase and laccase are enzymes which take part in the transformation of aromatic compounds. Peroxidase plays a major role in the process of demethoxylation of lignin and is produced by a number of soil fungi and bacteria species. Enzymes of the laccase-type cause the oxidation of phenols into quinones. This process can cause the breaking of the ether bonds between the aromatic subunits in the macromolecules of lignin, and eventually facilitate the breakdown of the aromatic ring itself (Trojanowski 1973). Both of these enzymes were found in the environment of humified plant material (Trojanowski et al., 1971).

Maximum peroxidase activity occurred after 4 weeks of incubation in all combinations (Fig. 107). Samples with sludge alone and samples with treated residue were characterized by the highest peroxidase activity. Maximal peroxidase activity in both combinations with control residues (CR and CRS) was less than in the sample with treated residue (TR). With further incubation peroxidase activity in all combinations, except TR, decreased to the end of the experiment. A second peak of activity found in the combination with treated residue (TR) can be attributed to renewed development of fungi which was disclosed by microbiological analyses. Mýsków (1963) found a correlation between organic matter degradation rates of legume plant roots and peroxidase activity. Such a dependence was not observed in this study since the most intensive degradation of plant material was found during the first month of incubation, and the maximum peroxidase activity was observed after this period.

The results exhibited in Figure 108 show a low level of laccase activity. Throughout the 16 week incubation period, activity of phenoloxidase did not exceed the value of 1 unit for all combinations, except treated residue (TR). An increase of laccase activity was evident between 16 and 24 weeks of incubation, especially in the combination with sludge and control residue (CRS). In the sample with treated residue (TR), laccase activity increased above 2 units after 4 weeks of incubation, followed by a decrease. The lower activity of laccase in our experiment in comparison to the activity found by Trojanowski et al. (1971) during the humification of rye roots may be attributed to pH differences between the two environments. The results reported here were obtained from an environment where pH was maintained between 6.6 and 8, whereas, the synthesis of laccase occurs most intensively at a pH of 4 to 5.

As shown in Table 64, considerable amounts of metals were present in sludge. Levels of metals, especially Cd, Zn, and Mn, were higher in treated residue than amounts in control residue, but many times lower than in the sludge.

Sludge mixed with control residue (in comparison with the control residue alone) had only a slight influence on the activity of enzymes and the rate of mineralization even though its addition supplied large quantities of heavy metals. Apparently the metals supplied as constituents of sludge were in biologically inactive forms (perhaps as sparingly soluble inorganic salts or organic complexes) under the conditions in which the study was conducted.

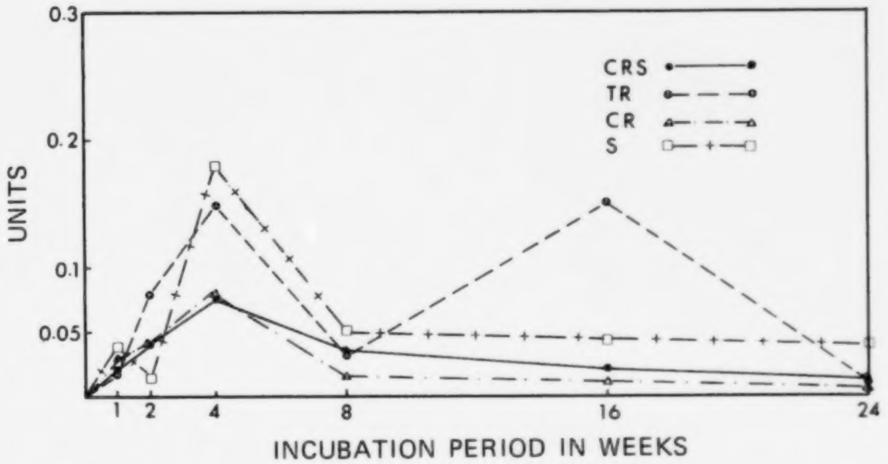

Figure 107. Peroxidase activity in samples of sludge, corn residues and sludge plus corn residue. Comparing control residues (CR) with treated residue (TR) activity was significantly different at the 0.05 probability level after 1 and 2 weeks of incubation and at the 0.01 probability level after 4, 8, and 16 weeks of incubation. Differences between control residue (CR) and control residues plus sludge were significant at 0.01 probability level for samples incubated 1, 8, 16, and 24 weeks.

451
107 = 571

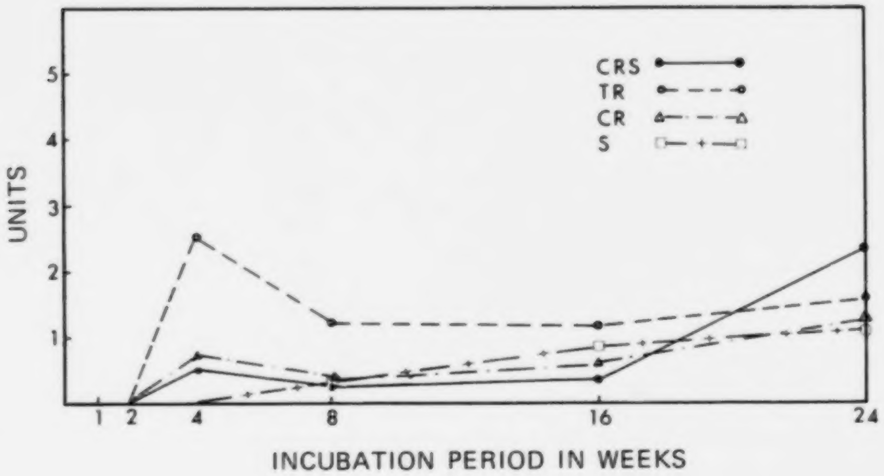

Figure 108. Phenoloxidase activity in samples of sludge, corn residues and sludge plus control residues. Comparing control residues (CR) with treated residues (TR), activity was significantly different at the 0.01 probability level after 4 and 8 weeks of incubation and at the 0.05 probability level after 18 weeks of incubation. Differences between control residue (CR) and control residues plus sludge (CRS) were significant at the 0.01 probability level for samples incubated 8 weeks and at 0.05 probability level for samples incubated 24 weeks.

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108—502

TABLE 64. MEAN CONTENTS OF SELECTED CHEMICAL ELEMENTS IN SLUDGE (S) AND RESIDUES (STALK AND LEAVES) OF CORN GROWN ON PLAINFIELD LOAMY SAND CONVENTIONALLY FERTILIZED CONTROL PLOTS (CR) AND PLOTS ANNUALLY TREATED WITH DIGESTED SLUDGE (TR) FROM 1969 TO 1975.

Sample	Element												
	C	Total-N	NH_4-N	NO_3-N	Zn	Fe	Mn	Mg	Ni	Cr	Pb	Cd	Cu
	--------% (d. wt.)---------				--------------------mg/kg (d. wt.)--------------------								
Control Residue (CR)	52.5	.755	.021	.084	25	68	20	3061	<0.625	<1	2	<1	5
Treated Residue (TR)	49.8	1.611	.024	.364	316	75	67	4151	6	1	3	17	7
Sludge (S)	23.3	2.580	.400	.014	4048	53929	686	25222	686	3220	993	231	1369

The variant demonstrating the lowest rate of mineralization, in spite of the highest level of enzyme activity and the lowest C:N ratio, was treated residues (TR). In this combination, metal levels were lower than where sludge was added directly to plant material (CRS).

In comparison to control residues (CR), the mineralization of residues from sludge-treated plots (TR) may have been inhibited because of higher contents of heavy metals. These metals probably formed tight bonds with polysaccharides making them more resistant to enzymatic hydrolysis. It is known that metals form salts or complexes with polysaccharides containing uronic groups (Mortensen 1963). Furthermore, a substantial percentage (33.4) of the cell walls in mature corn stalks consist of acid hemicellulose, a polysaccharide containing uronic groups (Siegel 1968). Considerable reduction in mineralization rate of plant and microbial polysaccarides as a result of bonding with metals was found by Martin et al. (1966).

Transformation of Nitrogen--

Results exhibited as Fig. 109 showed an increase of organic-N in all combinations containing plant material (CR, TR, CRS) during the first 4 weeks of incubation, paralleling the highest organic-C mineralization rate. The increase was relatively low, suggesting that growing microorganisms utilized the organic-N contained in sludge and plant material, rather than the mineral salts added to both combinations without sludge (CR and TR). The greatest relative increase in organic-N was found in the CR combination in which plant material was characterized by the smallest amount of organic-N. During the 4 to 8 week interval, amounts of organic-N in these samples decreased gradually, probably due to mineralization of secondary organic-N forms of microbiological origin.

Transformations of organic-N were different in the sample with sludge alone as compared to all other combinations with plant material. In this combination (S), organic-N decreased 29% during the first 4 weeks. Sludge organic materials containing N evidently provided easily available sources of C and energy for ammonifying microorganisms.

In the combination with plant material and added sludge (CRS) an increase in total-N was found between 16 and 24 weeks of incubation, which indicated that assimilation of N from the atmosphere may have occurred. This phenomenon was also observed in the combination with sludge alone between 4 and 8 weeks of incubation. This was not an isolated observation, because a similar process of N assimilation during the degradation of roots of legume plants in sand was found by Myśków (1963).

During incubation of samples, pronounced losses of N were observed in combinations without sludge (44% in CR and 34% in TR samples). Volatilization of ammonia was the apparent mechanism for losses of N supplied as NH_4NO_3. The neutral reaction of the environment was conducive to this process. In combinations with sludge, losses of N were neglible (about 17% after 16 weeks from CRS samples, and scarcely 9% after 24 weeks from S samples). Losses may have been low because the N supplied in sludge was present mainly in organic form and ammonia. Nitrogen in these forms was

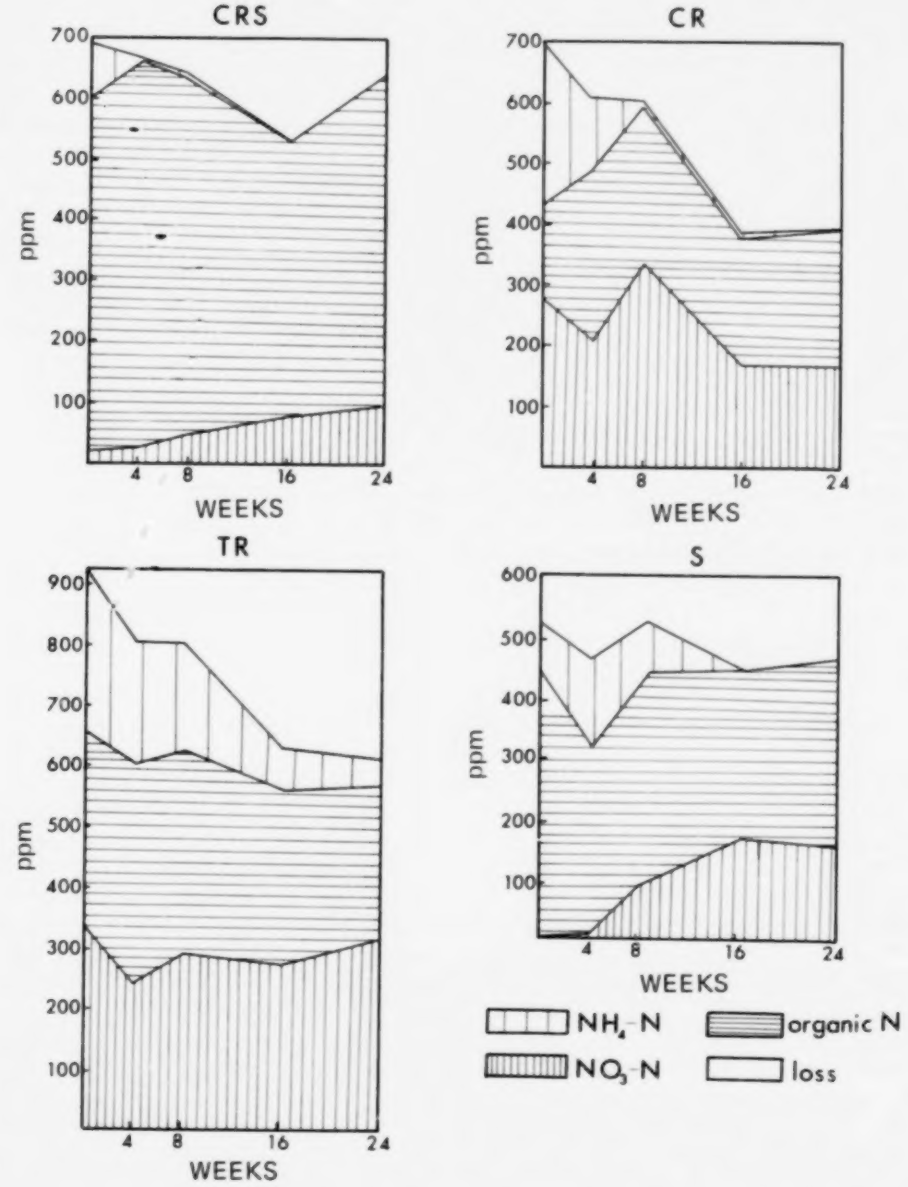

Figure 109. Transformations of nitrogen as shown by average amounts of NH_4-N, NO_3-N and organic-N in mixtures of sludge, corn residues, and sludge plus corn residues.

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109-566

gradually liberated in the ammonification process and transformed into nitrates. As pointed out earlier, the sludge used in this study had been dried so that much of the NH_4-N generally present in anaerobically digested sludge had already been volatilized. Nitrification occurred intensively in the combination with sludge alone as indicated by the high NO_3-N (154 mg/kg) at the end of incubation. Increases in NO_3-N concentrations were also observed in the combinations without sludge (CR and TR) and nitrification processes were clearly evident between 4 and 8 weeks of incubation. However, in both cases, amounts of NO_3-N were less at the end of incubation than initially, demonstrating the predominance of denitrification or immobilization of nitrates over the nitrification process.

Microorganisms--

The composition of mycoflora was similar in samples with control (CR) and treated residue (TR) as evident from results presented in Table 65. In both, *Humicola fusco-atra* and *Monodyctis levis* were dominant during the first 8 weeks of incubation. After 16 weeks, *H. fusco-atra* was eliminated and *Scopulariopsis* sp. in both combinations and *Chaetomium* sp. in the combination with treated residue were observed. During the whole incubation period, *M. levis* occurred in both CR and TR combinations.

In the combination with sludge addition (CRS) *H. fusco-atra* was dominant during the whole experimental period. According to Hirte (1961), representatives of this genus of fungi occur in fields repeatedly irrigated with sewage. Maliszewska et al. (1975) found this genus in soils with high concentrations of Cd. Domsch and Gams (1972) indicated that *H. fusco-atra* occurs mainly in soils with a neutral reaction. It is principally known as an organism which decomposes cellulose and produces the C_1 enzyme in greater quantities than C_x. According to Reese and Levinson (1952) the C_1 component of cellulolytic complexes is responsible for the initial modification of crystalline cellulose for enzymatic hydrolysis carried out by the C_x component. In the same combination (CRS), a considerable percentage of *Streptomyces* sp. was found at one sampling period. In the vicinity of sand grains where *Streptomyces* sp. was growing *H. fusco-atra* was not observed, suggesting an antagonistic effect of the actinomycetes on fungus. In this combination *M. levis* also occurred, but in a smaller percentage than in both combinations without sludge (CR and TR). *M. levis* grew slower on the medium with filter paper and degraded substrate to a lesser degree than *H. fusco-atra*. Because of this observation, it is likely that *Humicola* played a more important role in the degradation of cellulose, being a more active and rapid growing species. *Botryotrichum piluliferum*, *Fusarium* sp., *Trichoderma* sp. and black nonsporulating mycelium were observed sporadically in the same combinations in various stages of incubation.

During the first 2 weeks of incubation, when the synthesis of cellulolytic enzymes was most intensive, the difference in percentages of sand grains colonized by fungi between samples was not substantial. However, the combination with treated residue (TR) was characterized by a slightly higher amount of cellulolytic fungi, which was positively correlated with the higher activity of cellulases. The percentage of grains surrounded by fungi after a

TABLE 65. PERCENTAGE OF SAND GRAINS IN CELLULOSE MEDIUM OCCUPIED BY FUNGI AND ACTINOMYCETES AND PERCENT DISTRIBUTION OF GENERA IN CELLULOLYTIC FUNGI AND ACTINOMYCETES POPULATIONS FROM INCUBATED SAMPLES OF SLUDGE, CORN RESIDUE, AND SLUDGE PLUS CORN RESIDUES AFTER 2, 4, 8, 16, AND 24 WEEKS.

Sample	Weeks of incubation	%[1]	Genera				
			Humicola fusco-atra	Monodyctis levis	Chaetomium sp.	Scopulariopsis sp.	Others
			---------------% of total population on inhabited grains--------------				
CR	2	43.4	40	20	10	0	18[2], 12[3]
	4	89.1	37	58	0	0	5[2]
	8	100.0	33	40	19	0	8[4]
	16	82.1	3	55	2	20	2[2], 16[5], 2[4]
	24	77.7	0	73	0	17	10[3]
TR	2	60.7	45	30	17	0	8[3]
	4	79.3	73	27	0	0	-
	8	100.0	46	50	4	0	-
	16	69.4	0	3	58	24	15[5]
	24	81.9	0	38	13	49	-
CRS	2	53.5	62	29	6	3	-
	4	100.0	74	19	0	0	7[6]
	8	100.0	76	11	0	0	13[2]
	16	89.0	78	4	2	0	16[5]
	24	69.4	75	0	25	0	-

(continued)

TABLE 65. (continued)

Sample	Weeks of incubation	%1/	Genera Humicola fusco-atra	Monodyctis levis	Chaetomium sp.	Scopulariopsis sp.	Others
			---------------% of total population on inhabited grains				---------------
S	2	4.9	75	0	25	0	-
	4	17.0	100	0	0	0	-
	8	19.5	93	0	7	0	-
	16	15.2	62	0	38	0	-
	24	22.2	32	42	25	0	-

1/ Percentage of grains with fungi and actinomycetes
2/ *B. piluliferum*
3/ *Fusarium* sp.
4/ Nonsporulating black mycelium
5/ *Streptomyces* sp.
6/ *Trichoderma* sp.

2-week incubation was not as high as had been anticipated from the rate of mineralization and the increase of enzymatic activity. One-hundred percent colonization was found after 4 or 8 weeks (Table 65) suggesting fungi occurred in an active mycelium form at the beginning and sporulated later.

Considerable number of cellulolytic bacteria were found in the combination with sludge (CRS) and smaller numbers in the combination with control residue (CR) (Table 66). These findings suggest that sludge in the presence of plant material stimulated the development of cellulolytic bacteria which may have been responsible along with fungi for degradation of cellulose.

After discovering phenoloxidase activity in the samples, an analysis of fungi able to grow in the medium with lignin was conducted. Fungi Imperfecti sporulated very well on this medium, and in most cases this facilitated the direct observation of fungi on plates. Investigations carried out after 8 weeks of incubation showed that in every combination with plant residue, all the sand crumbs were surrounded by fungi, and more than one species usually occupied a sand grain. On the other hand, in the sample with sludge alone (S), approximately 50% of the sand crumbs were inhabited by fungi. The most evident differences between samples were the domination of *Scopulariopsis* sp. in the combination with treated residue (TR) at all stages of incubation; domination of *Humicola fusco-atra* in the sample with sludge added (CRS), as well as the elimination of *Doratomyces microsporus* in the presence of sludge (Table 67). The last observation is contrary to the findings of Hirte (1961), who isolated this fungus from fields irrigated with sewage effluents. Besides the species listed in Table 67, *Fusarium roseum* was found in all examined combinations. The extent to which sand grains were surrounded by this fungus was difficult to determine because its scant mycelium was scattered throughout the medium and not confined to clearly delineated colonies.

The last analysis, carried out after 24 weeks, showed reddening of lignin medium inoculated with sand crumbs from all combinations. A similar phenomenon was observed by Westernmark and Eriksson (1974) when *Polyporus versicolor* was grown on the medium with the same lignin substrate. They found laccase activity in all areas which were visibly red. Therefore, the color probably originated from phenoloxidase oxidation of p-pheny-lenediamine or lignin in our study. The zones of reddening were observed around 76% of the sand grains from the sample with control residue (CR) and 50% of grains from the treated residue sample (TR). However, in both combinations (CR and TR) color was not intense and did not spread from the sand crumbs. In the combination with sludge and control residue (CRS), an intense brown-red color was observed around all sand grains. At the same time, phenoloxidase activity increased and, to the greatest extent, in the combination with sludge addition. Microscopic analyses revealed the presence of Fungi Imperfecti and Ascomycetes. According to Trojanowski (1973), fungi belonging to these two classes are characterized by the absence of exophenoloxidase, in spite of the fact that many of then are able to degrade lignin. Because the red color appeared after 4 to 5 days of incubation on plates, as mycelium began to grow, it was less likely that enzymes from lysed mycelium caused the reddening of the medium. The diversity of genera of fungi found on the medium with lignin

TABLE 66. TOTAL NUMBER OF CELLULOLYTIC BACTERIA/G OF MIXTURES OF SLUDGE, CORN RESIDUES, AND SLUDGE PLUS CORN RESIDUES.

Incubation time in weeks	Sample			
	CR	TR	CRS	S
1	4	5	116	0
2	548	5	13400	51
4	54	5	5420	28
8	299	5	16700	0
24	30	10	1147	0

TABLE 67. RANGES OF PERCENTAGE OF SAND GRAINS IN LIGNIN MEDIUM INHABITED BY DIFFERENT GENERA OF FUNGI.*

Sample	Incubation time in weeks	Percentage		
		51-100	25-50	<25
CR	8	*M. levis*		*H. fusco-atra* *Scopulariopsis* sp.
	16	*Scopulariopsis* sp., *D. microsporus*, *Penicillium* sp.	*M. levis*	*Botryotrichum* sp.
	24	*Scopulariopsis* sp., *D. microsporus*, *M. levis*		*Penicillium* sp.
TR	8	*Scopulariopsis* sp., *M. levis*, *Fusidium* sp.	*H. fusco-atra*	
	16	*Scopulariopsis* sp., *D. microsporus*	*Chaetomium* sp.	*M. levis*
	24	*Scopulariopsis* sp.	*M. levis*, *D. microsporus*	
CRS	8	*H. fusco-atra*		*Scopulariopsis* sp.
	16	*H. fusco-atra*	Nonidentified black mycelium	*Chaetomium* sp., *M. levis*
	24	*H. fusco-atra*, *Scopulasiopsis* sp., *M. levis*	Nonidentified black mycelium	*Gliocladium* sp.

(continued)

TABLE 67. (continued)

Sample	Incubation time in weeks	Percentage		
		51-100	25-50	<25
S	8		*M. fusco-atra*	*Scopulariopsis* sp.
	16		*M. fusco-atra* *Scopulariopsis* sp., *Gliocladium* sp., *Penicillium* sp.	
	24			*Scopulariopsis* sp., *M. levis*

*Sand grains were transferred from samples of sludge, corn residues and sludge plus corn residues.

was similar to that occurring on the medium with cellulose, indicating that the same species were able to use both sources of carbon. Most of these species are mentioned by Domsch and Gams (1972) as able to degrade cellulose and lignin.

Martin's medium is very often used for determination of total count of soil fungi. However, in our study fungi belonging to Mucoraceae: Circinella sp. and Mucor sp. predominated on this medium, forming 70 to 90% of colonies in all combinations during the first 8 weeks of incubation. Fungi belonging to this family are able to use simple sugars and only some use modified soluble cellulose as a carbon source (Griffin 1972). In the combination of control residue and sludge (CRS), these fungi were the most abundant and occurred during the whole incubation period (Table 68). Their growth and sporulation were perhaps stimulated as a result of higher amounts of organic forms of nitrogen incorporated with sludge, which they were able to degrade because they possessed active proteolytic enzymes. Because of the domination of Circinella sp. and Mucor sp., and their very rapid growth on this medium, the other fungi occurring in samples were discovered only by using selective media. After 2 weeks of incubation the two dominant species reached maximum numbers in all combinations with plant material after which time their population decreased. Their numbers probably decreased because of decreasing amounts of available sugars released during hydrolysis of polysaccharides. The increase of total numbers of fungi after 16 weeks of incubation in both samples without sludge (CR and TR), as shown in Table 68, was associated with the develpment of other genera and total elimination of Mucoraceae. Fungi such as Scopulariopsis sp. (80%) and Doratomyces microsporus (20%) were dominant in control residue (CR), whereas Scopulariopsis sp. (51%) and Chaetomium sp. (36%) were dominant in treated residue (TR) samples.

Results presented in this study confirmed the classical succession occurring during the colonization of plant residues. According to Griffin (1972) the first group of fungi are Phycomycetes which have been considered to be "sugar fungi"; the next group are Ascomycetes and Fungi Imperfecti which are known as cellulolytic. More recent works, however, have shown representatives of these latter two groups can also take part in lignin degradation (Eslyn et al. 1975). Basidiomycetes, which are very active lignin decomposers, were not observed even though phenoloxidase activity usually attributable to these fungi was present.

In the combination with sludge addition (CRS), where organic matter was the most varied, the highest amounts of bacteria were found (Table 69). As with Mucorales, the numbers of bacteria in all combinations with plant material were highest after 2 weeks of incubation. Total numbers decreased later, probably as a result of decreasing amounts of easily available sugars released during the hydrolysis of plant polysaccharides. Samples with sludge alone were characterized by lowest numbers of microorganisms, except for analyses carried out after one week where bacteria numbers were highest. This may have been the result of reduced competition between bacteria and other groups of microorganisms during the early stages of decomposition. Numbers of fungi in this combination were lowest and the occurrence of actinomycetes was not observed until the last analyses.

TABLE 68. TOTAL NUMBER OF FUNGI IN MIXTURES OF SLUDGE, CORN RESIDUES AND SLUDGE PLUS CORN RESIDUES.

Incubation time in weeks	Sample			
	CR	TR	CRS	S
	thousands per gram			
1	732	1122	7682	40
2	744	5691	7845	33
4	579	1207	4132	25
8	375	422	2630	0.2
16	2129	2782	1607	1.6
24	375	1309	978	0.1

TABLE 69. TOTAL NUMBER OF BACTERIA (B) AND ACTINOMYCETES (A) IN MIXTURES OF SLUDGE, CORN RESIDUES, AND SLUDGE PLUS CORN RESIDUES.

Incubation time in weeks	Sample							
	CR		TR		CRS		S	
	B	A	B	A	B	A	B	A
	millions per gram							
1	449	125	425	141	992	110	1130	0
2	511	128	866	93	1567	230	364	0
4	99	104	279	164	339	40	124	0
8	93	10	134	8	228	18	64	0
16	44	0.8	53	0.1	151	1	28	0
24	76	0.4	147	1	210	14	63	0.2

Comparing all the combinations with plant material, some analogies in microbial populations were found. Populations were most similar in both samples with plant residues without sludge (CR and TR). But judging from the rate of mineralization, the activity of microorganisms on plant substrate was more efficient in combination with control residue (CR). The combination with control residue and sludge (CRS) differed to some extent from the others largely due to the different forms of organic and inorganic constituents. The particular effect of metals on the growth of specific microorganisms was difficult to separate from nutritional factors in such a complex environment.

Based on results in the literature (41) and findings from this study, it appears that the way metals affect activity of microorganisms depends on the form in which the metals exist. Although, sludge mixed directly with plant residue did not have an inhibiting effect on the mineralization of organic-C, it would be worthwhile to determine if the effect of sludge is dependent on the pH of the environment. Where lower pH conditions exist, metals occurring in soluble salts and chelate forms have generally been found to exhibit evident biological effects. It was found from our studies that applications of sludge on soil causing enhanced uptake of metals by plants may, to some degree, indirectly influence the mineralization process of such plant residues. Important factors affecting mineralization of plant residues are probably chemical composition of residue organic fractions, quantities of metals assimilated by plants, and amounts of a particular metal species relative to total metal contents. Martin's (22) findings showed that the effect of metals on mineralization of polysaccharides depended on the chemical nature of materials. Because it was found in this study that cellulase activity was increased in the presence of elevated levels of metals in plant materials (Figure 2), measurements of enzyme activities may not be an indicator of the rate at which such materials will be hydrolyzed in soils. These results suggest the need for further studies to assess the affect of various levels of plant assimilated metals on the induction of enzymatic activity and consequential hydrolysis of hemicellulose and pectin materials incorporated into soils as constitutents of plant residues.

PHYSICAL AND CHEMICAL CHANGES IN SEWAGE SLUDGE-AMENDED SOIL AND FACTORS AFFECTING THE EXTRACTABILITY OF SELECTED CHEMICAL ELEMENTS

General Description

Establishing a relationship between amounts of a particular element extracted from soils with amounts assimilated by plants is complicated because both may be affected either directly or indirectly by soil temperature, pH, contents of calcium carbonate, clay, P, organic matter, and moisture. Furthermore, assimilation of both nutrient and nonnutrient elements varies by plant species, varieties within plant species, concentration balances maintained between soluble chemical elements in soil solutions, and environmental factors affecting plant growth and development. Nevertheless, as a first step in developing methods of predicting phytotoxic levels of chemical elements in soils from convenient measurements of extractable quantities, information is needed with regard to how such quantities are altered by changes in chemical and physical properties of soils. For example, when chemical elements are added to soils as constituents of waste materials, physical properties of soils may also be changed. Soil temperature and moisture regimes may vary from year to year reflecting variations in climatic conditions. Where large numbers of soil samples must be collected during specific short periods of time, adequate laboratory space, free from potential sources of contamination, may not be available for air-drying of samples. Thus, it may be necessary at times to store samples in a moist state until air drying facilities are available or shorten the period of drying by using forced-air ovens. These factors may influence the extractability of some chemical elements more than others as well as contributing to higher or lower quantities being extracted by a strong acid like HCl as compared to a weak acid such as CH_3COOH. Comparative results for HCl and CH_3COOH are needed to relate published findings obtained from the use of one extractant to results obtained by the use of the other.

In a review of soil testing procedures, Viets and Lindsay (1973) said "More extraction and calibration work has probably been done with HCl than with any other acid". They cited a long list of sources as a basis for the statement. Next to HCl, acetic acid (CH_3COOH) has probably been the most popular extractant for assessing heavy metal levels in soils (Hibbard, 1940; Mitchell, 1945; Tucker and Kurtz, 1955; Mitchell et al., 1957; Fiskell et al., 1964; LeRiche, 1968; Purves and Mackenzie, 1969; Goodman and Roberts, 1971; Berrow and Webber, 1972; Little and Martin, 1972; and Purves, 1972). Strengths of acids most commonly employed by researchers were 0.1 $\underline{N}$ HCl and 0.5 $\underline{N}$ or 2.5% CH_3COOH. Apparently, these acids were used because they required a minimum of labor and extracted a representative quantity of total contents of several chemical elements from soils which could subsequently be determined directly by spectroscopic technique.

Objectives of the study reported here were as follows: (1) Determine changes in chemical and physical properties of a soil which had been annually irrigated with anaerobically digested municipal sewage sludge during 6 successive growing seasons; (2) Investigate changes in 0.1 $\underline{N}$ HCl and 2.5% CH_3COOH extractable quantities of P, Fe, Mn, Zn, Cu, Ni, Cr, Cd, and Pb from control and sludge-amended soils resulting from sample storage and methods of drying; and (3) Employing the same two acids, examine changes in extractable levels of the previously listed elements in soil samples adjusted to different moisture contents and incubated at different soil temperatures.

Twenty-five surface samples (Ap horizon, 0-15 cm depth) of Blount silt loam (Aeric ochraqualf, fine illitic, mesic) soil from each of 4 replicated control and sludge-amended plots, measuring 6.1 by 12.2 m, were collected by using stainless steel soil sampling tubes in May, 1974. These plots were established in 1968 to measure the response of corn (*Zea mays* L.) to long-term annual applications of digested municipal sewage sludges and were described in Section II of this report. On maximum sludge treated plots, accumulative solids (dry weight equivalent) incrementally applied during the 6 years, amounted to 369 mt/ha in 1974.

Subsamples of soil from each plot were thoroughly mixed and a portion of each composite sample was stored in polyethylene lined disposal bags in a cool room maintained at about 8°C. After these samples had been stored from the first week in May, 1974 to the last week of April, 1975, they were subdivided into three portions, of which one was air-dried, one was oven-dried at 60°C, and one was oven-dried at 110°C before being extracted with 0.1 N HCl and 2.5% CH_3COOH and analyzed for extractable concentrations of P, Fe, Mn, Zn, Cu, Ni, Cr, Cd, and Pb. Soon after collection, part of each composite soil sample was air-dried, crushed in an agate mortar to pass through a 60-mesh sieve, and used for determinations of particle-size distribution, cation exchange capacity, levels of exchangeable cations, total and available water holding capacity, pH, and total contents of several chemical elements.

Directly after the soil samples were collected, a portion was oven-dried at 60°C from which extracts with 0.1 N HCl and 2.5% CH_3COOH were analyzed for concentrations of selected chemical elements. These data were obtained for the purpose of comparing levels in similar portions of soil stored for approximately one-year in a field moist state before drying at 60°C in a forced-air oven. Following determinations of actual soil moisture contents and total water-holding capacities in 1974, the equivalent of 300 g (d.w.) of soil from each plot was placed in each of nine glass bottles. Then soil moisture contents were adjusted to 30, 60, or 90 percent of total water holding capacity in each of 3 samples. Subsequently, one of the 3 samples having a particular moisture content was incubated at 4-, 20-, or 30-°C for a period of 30 days.

Total and extractable concentrations of Ca, Mg, Fe, Mn, Cu, Zn, Cr, Cd, Ni, and Pb in solutions were determined by atomic absorption and K and Na in solutions were determined by flame photometry techniques. Total concentrations were determined after ashing 0.5 g soil samples at 500°C, followed by two digestions in concentrated HCl-HF. After the last digestion, ashes were dissolved in 1.0 N HCl and quantitatively transferred to 25 ml volumetric flasks and diluted to volume. Extracts from dried soil samples were prepared by shaking 1.0 g of soil for 2 hours with 20 ml of 0.1 N HCl or 2.5% CH_3COOH. Incubation effects on concentration levels were measured by extracting 10 g of moist soil with 200 ml of appropriate acid and determining the moisture content at the time of extraction preparatory to expressing results on a dry weight basis. Phosphorus concentrations in solutions were determined colorimetrically using the vanadomolybdate (yellow) method. Determinations of soil organic carbon contents were made by the wet combustion method as described by Allison et al. (1965) and total organic nitrogen contents by the macro-Kjeldahl method, to include both nitrate and nitrite, as described by Bremner (1965).

Other methods employed were as follows: (1) Particle size distribution was determined by the pipette method (Day, 1965); (2) Percent water-stable aggregates was determined by the method of Kemper and Chepil (1965), except that only the 0.25 mm sieve was used; (3) Cation exchange capacity was determined by the method described by Chapman (1965); (4) Individual exchangeable cations were determined in the leachate of neutral 1 N NH_4OAc after concentrating by evaporation and digestion of residues with concentrated HNO_3; (5) Total water holding capacity was determined by the use of Kopecky's cylinders; (6) Available water holding capacity was determined by pressure chamber equipment as discussed by Richards (1965); (7) Using a Corning model 12 pH meter, measurements of pH were made in soil at solution ratios of 1:2.5 for both distilled water and 1.0 N KCl; and (8) Bulk density was determined by the core method as described by Blake (1965).

Discussion of Results

Changes in Chemical and Physical Properties of Blount Silt Loam--

Results presented in Table 70 show that the incorporation of 369 mt/ha of dry solid residuals of liquid sludge suspensions applied by furrow irrigation on Blount silt loam in more or less equal increments over a period of 6 years caused significant increases in several plant nutrient and non-nutrient elements. Soil contents of organic carbon and total nitrogen were increased more than 2-fold. The C to N ratios were 11.5 and 11.7 respectively for control and sludge-amended plots and, thus, not significantly different. Sludge applications caused a 4.4-fold increase in total P. With the exception of Fe and Mn, soil contents of all heavy metals were significantly increased by sludge applications. On a proportional basis, Cd was increased to the greatest extent. Potassium, Mg, and Na contents were about the same in control and sludge-amended soil. Liming of soils probably was the major cause of differences in Ca levels.

Although not significantly different, it was observed from the data presented in Table 71 that, exchangeable Ca concentrations in sludge-amended soil tended to be higher than in control soils. Exchangeable levels of Mg and Mn were not affected by sludge treatments. Contrary to the lack of differences in contents of total K and Na as a result of treatment, exchangeable levels of both elements were significantly greater in sludge-amended soil. Solutions from samples of soil from control plots contained levels of Fe and Cd below detectable limits of 0.05 and 0.01 mg/kg, respectively, while measureable quantities were recorded in Table 71 for samples from sludge-amended plots. Thus it was presumed that differences in exchangeable Fe and Cd were due to treatment effects. Exchangeable levels of Zn, Cu, and Ni were all significantly higher in sludge-amended soil, but exchangeable Cr and Pb concentrations were below detectable limits in all samples regardless of treatment.

As shown in Table 72, the pH was not significantly different between control and sludge-amended soil, even though the latter had lower values of 0.1 to 0.2 units. Relatively high annual applications of digested sludge caused a significant increase of 2.5 me/100 g in soil cation exchange capacity. The percent base saturation was not significantly different between treatments. About the same situation existed with regard to heavy metals. Exchangeable concentrations of several heavy metals were higher in sludge-amended soils, but total exchangeable concentrations as a percent of the cation exchange capacity were not significantly different. Digested sludge applications increased the total water holding capacity of the soil along with increased amounts of moisture held in the soil at tensions of 1/3 and 15 atmospheres. If available water holding capacity is calculated by the conventional procedure of subtracting moisture contents at 15 atmospheres from those at 1/3 atmospheres, it was observed that no differences existed between

TABLE 70. RANGE AND MEAN FOR TOTAL CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN REPLICATED CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS[a]/

Element		Treatment		
		Control	Sludge-amended	LSD
		%		
Org. C	range	1.30-1.52	2.99-3.35	
	mean	1.43	3.23	0.46**
N	range	0.114-0.135	0.236-0.294	
	mean	0.124	0.276	0.075**
P	range	0.068-0.078	0.270-0.352	
	mean	0.073	0.322	0.112**
K	range	1.447-1.716	1.570-1.646	
	mean	1.620	1.605	n.s.
Ca	range	0.590-0.743	0.930-1.203	
	mean	0.645	1.045	0.262*
Mg	range	0.308-0.369	0.331-0.367	
	mean	0.345	0.357	n.s.
Na	range	0.709-0.785	0.732-0.756	
	mean	0.765	0.744	n.s.
Fe	range	1.631-2.210	2.091-2.259	
	mean	1.917	2.207	n.s.
Mn	range	0.132-0.188	0.118-0.206	
	mean	0.161	0.165	n.s.
		ppm		
Zn	range	76.57-104.65	353.91-491.75	
	mean	85.36	434.67	173.43**
Cu	range	16.21-20.78	94.72-117.01	
	mean	17.84	108.60	32.03**
Ni	range	21.11-26.00	35.25-38.40	
	mean	24.47	37.44	9.09**

(continued)

TABLE 70. (continued)

Element		Treatment Control	 Sludge-amended	LSD
		ppm		
Cr	range	32.03-38.93	153.57-199.38	
	mean	35.31	184.30	67.93**
Cd	range	1.66-2.88	17.67-20.73	
	mean	2.08	19.63	4.61**
Pb	range	27.93-33.54	103.67-126.49	
	mean	31.60	115.20	29.47**

a/ Dry weight.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. Not significantly different.

TABLE 71. RANGE AND MEAN CONCENTRATIONS OF EXCHANGEABLE CATIONS IN CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS.[a]

Element[b]		Treatment		
		Control	Sludge-Amended	LSD
		me/100g		
Ca	range	7.36-10.07	10.51-11.26	
	mean	8.82	10.89	n.s.
Mg	range	0.80-1.13	0.72-0.86	
	mean	0.93	0.79	n.s.
K	range	0.69-0.86	1.03-1.45	
	mean	0.75	1.22	0.42*
Na	range	0.05-0.06	0.11-0.12	
	mean	0.05	0.11	0.02**
Fe	range	bdl	0.0090-0.0101	
	mean	bdl	0.0096	
Mn	range	0.1029-0.1521	0.1268-0.1882	
	mean	0.1272	0.1474	n.s.
Zn	range	0.0008-0.0018	0.0372-0.0463	
	mean	0.0012	0.0416	0.0102**
Cu	range	0.0007-0.0009	0.0088-0.0126	
	mean	0.0008	0.0102	0.0049**
Ni	range	0.0012-0.0028	0.0028-0.0040	
	mean	0.0017	0.0032	0.0015*
Cd	range	bdl	0.0030-0.0040	
	mean	bdl	0.0037	

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[a] Dry weight.

[b] Chromium and Pb were below detectable limits in all samples.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s. Not significantly different

bdl Below detectable limits

TABLE 72. SELECTED CHEMICAL AND PHYSICAL PROPERTIES OF CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM PLOTS (0-15 cm DEPTH).

Property			Treatment		
			Control	Sludge-amended	LSD
pH 1:2.5	H_2O	range	6.4-7.2	6.6-6.7	
		median	6.8	6.6	n.s.
	KCl	range	5.9-6.7	6.1-6.3	
		median	6.3	6.2	n.s.
			----------------------me/100g----------------		
Cation Exchange Capacity		range	11.08-12.80	13.44-15.51	
		mean	11.65	14.16	0.73**
			----------------------% of CEC--------------		
Base Saturation		range	79.6-100.0	85.9-95.9	
		mean	91	92	n.s.
Heavy Metal Saturation		range	0.91-1.33	1.31-1.78	
		mean	1.12	1.50	n.s.
			-----------------% of oven-dried soil------		
Total Water-Holding Capacity		range	48.29-49.78	58.55-60.72	
		mean	49.10	59.45	3.32**
Moisture Content	1/3 atm	range	28.78-30.18	31.05-33.72	
		mean	29.74	32.62	1.98**
	15 atm	range	8.53-9.63	11.55-12.95	
		mean	9.19	12.43	2.17**
			------------------% > 0.25 mm-------------		
Water Stable[a/] Aggregates		mean	9.74	22.80	3.39**
			----------------------g/cm^3--------------		
Bulk Density		range	1.32-1.49	0.82-1.21	
		mean	1.41	1.14	0.104**

[a/] Determined in 1973 when accumulative sludge applications were equivalent to 306.5 mt/ha (d.w.).

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

n.s. Not significantly different.

control and sludge-amended soils. Long-term applications of sludge markedly improved soil structural properties as expressed by the significant increase in percentage of water-stable aggregates and decreased bulk density in the surface of soil in sludge-amended plots.

Effects of Drying on Extractable Concentrations of Selected Elements--
Data presented in Tables 73 and 74 show that drying of soil samples either by air-drying or in forced-air ovens at temperatures of 60 to 110°C had little affect on levels of P, Zn, Cu, Cr, and Cd extracted with either 0.1 N HCl or 2.5% CH_3COOH. When samples of control soils were dried in forced-air ovens, 0.1 N HCl and 2.5% CH_3COOH extractable Fe levels were increased over levels in air-dried soil. But differences in extractable Fe levels attributable to methods of drying sludge-amended soil were not observed by the use of either extractant. On the other hand, levels of Mn extracted with either 0.1 N HCl or 2.5% CH_3COOH were increased in samples of both control and sludge-amended soil by oven drying as compared to air drying. Levels of Ni extractable with 0.1 N HCl from control soil were decreased by oven-drying as compared to levels in air-dried samples, but not in sludge-amended soil. Amounts of Ni extracted with 2.5% CH_3COOH were not affected by methods of drying in either control or sludge-amended soil. Like Ni, levels of Pb extracted with 0.1 N HCl were less in soil from control plots dried at higher temperatures in ovens, but not in samples from sludge-amended plots. Lead concentrations were below detectable limits in 2.5% CH_3COOH extracts of both control and sludge-amended soil samples subjected to different methods of drying.

Effects of Storage on Extractable Concentrations of Selected Elements--
Levels of selected chemical elements extractable with 0.1 N HCl and 2.5% CH_3COOH from samples dried at 60°C immediately after sampling operations with extractable levels in split-samples stored for approximately one year at 8°C before drying at 60°C are also presented for comparison in Tables 73 and 74. Storage resulted in increased levels of 0.1 N HCl extractable P in samples from both control and sludge-amended soils; but 2.5% CH_3COOH extractable levels were not changed. Levels of Fe were increased by storage in 0.1 N HCl extracts of samples from control, but not sludge-amended plots. Iron levels in 2.5% CH_3COOH extracts were changed by storage of control soil but were decreased by storage of sludge-amended soil. Levels of Mn extracted with either 0.1 N HCl or 2.5% CH_3COOH were not affected by storage in samples from either control or sludge-amended soil. In soil samples from control plots, levels of Zn, Cu, Cr, Cd, and Pb extractable with 0.1 N HCl were not affected by storage; but extractable levels of these elements in samples from sludge-amended plots were increased by storage. An analogous situation existed for 2.5% CH_3COOH extractable Cu, Ni, Cr, and Cd. Levels of these metals in CH_3COOH extracts of control soil were not affected by storage; but concentrations in similar extracts of sludge-amended soils were significantly higher after storage. Amounts of Zn extracted by 2.5% CH_3COOH were increased by storage of both control and sludge-amended soil samples.

It was observed in every instance except one, that higher proportions of total soil concentrations of the several chemical elements were extracted by both acid extractants from sludge-amended soil than from control soil, where samples were dried at 60°C immediately after collecting in 1974. The one

TABLE 73. MEAN CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS EXTRACTED WITH 0.1 N HCl FROM REPLICATED CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM SOIL (0-15 cm DEPTH) SUBJECTED TO DIFFERENT METHODS OF DRYING AND LENGTH OF STORAGE.[a]

			Dried 1975			Dried 1974	
Element			Air-dried	60°C	110°C	60°C	LSD
			----------ppm (dry weight)----------				
P	Control	range means	143.4-178.7 161.0	138.2-150.1 144.7	134.2-154.7 144.4	82.9-129.2 98.8	30.8**
	Sludge-amended	range means	1217.8-1923.7 1512.9	1137.5-1726.9 1457.0	1190.8-1455.0 1290.9	935.2-1079.8 1033.6	311.8*
Fe	Control	range means	270.2-434.4 367.6	388.0-546.4 457.4	422.2-610.8 543.2	299.8-447.4 354.1	102.8**
	Sludge-amended	range means	1385.0-1945.0 1665.7	1322.7-1849.9 1621.0	1560.9-1794.5 1685.3	1203.1-1592.9 1331.6	n.s.
Mn	Control	range means	161.8-245.3 205.9	305.8-347.7 327.0	389.6-502.7 428.5	225.5-408.8 317.5	101.2**
	Sludge-amended	range means	381.5-564.4 488.7	397.7-677.7 536.8	615.8-818.5 698.9	361.8-449.7 405.4	145.5**
Zn	Control	range means	13.6-25.6 18.4	16.0-26.3 20.1	16.2-23.1 18.2	14.0-23.9 16.9	n.s.
	Sludge-amended	range means	283.9-392.1 330.6	249.8-346.5 307.3	279.4-350.5 326.2	203.2-286.7 239.1	66.5*
Cu	Control	range means	3.7-6.8 4.9	4.4-5.8 4.8	4.0-5.7 4.7	4.4-7.1 5.4	n.s.
	Sludge-amended	range means	65.1-91.4 76.5	63.6-80.4 72.7	61.3-79.3 70.9	50.9-60.5 55.6	15.6**

(continued)

TABLE 73. (continued)

Element			Dried 1975			Dried 1974	
			Air-dried	60°C	110°C	60°C	LSD
			ppm (dry weight)				
Ni	Control	range	2.2-3.2	1.9-3.2	1.6-2.1	2.2-4.2	
		means	2.6	2.5	1.7	3.2	0.89*
	Sludge-amended	range	9.9-15.1	7.3-11.4	10.2-14.3	7.8-9.4	
		means	12.6	9.4	12.6	8.6	3.0**
Cr	Control	range	1.4-2.9	0.97-2.2	0.95-2.6	1.00-2.3	
		means	2.0	1.4	1.9	1.6	n.s.
	Sludge-amended	range	62.2-100.0	61.1-82.8	57.9-77.1	37.4-49.5	
		means	75.4	71.9	69.1	43.4	21.3**
Cd	Control	range	0.63-0.94	0.62-0.93	0.72-0.92	0.61-1.3	
		means	0.81	0.75	0.82	0.88	n.s.
	Sludge-amended	range	14.5-20.1	14.8-17.5	13.8-17.4	10.9-13.9	
		means	16.9	16.3	16.0	12.5	1.5*
Pb	Control	range	7.4-9.7	9.1-11.3	10.6-11.7	7.0-9.9	
		means	8.5	10.2	11.2	8.7	1.7*
	Sludge-amended	range	66.0-81.9	65.6-79.4	64.6-73.5	47.9-61.6	
		means	72.3	73.0	70,7	55.9	10.2*

a/ Samples were collected in 1974, but portions were not dried until 1975.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. Not significantly different

TABLE 74. MEAN CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS EXTRACTED WITH 2.5% CH_3COOH FROM REPLICATED CONTROL AND SLUDGE-AMENDED BLOUNT SILT LOAM SOIL (0-15 cm DEPTH) SUBJECTED TO DIFFERENT METHODS OF DRYING AND LENGTH OF STORAGE.[b]

Element[a]			Dried 1975			Dried 1974	
			Air-dried	60°C	110°C	60°C	LSD
			ppm (dry weight)				
P	Control	range	63.1-95.8	64.1-77.1	62.7-79.3	61.7-111.8	
		means	73.1	72.9	68.4	77.8	n.s.
	Sludge-amended	range	259.5-339.4	263.4-344.4	250.9-295.3	244.6-255.1	
		means	293.3	295.4	278.8	250.5	n.s.
Fe	Control	range	3.1-5.0	4.0-5.9	6.3-7.7	2.6-7.4	
		means	4.4	5.1	7.0	4.0	2.2**
	Sludge-amended	range	6.9-10.8	9.3-12.6	12.9-16.6	40.7-67.9	
		means	9.1	10.8	14.3	55.0	17.6**
Mn	Control	range	66.4-104.1	119.2-142.0	177.5-243.5	129.2-209.2	
		means	82.6	130.6	218.2	168.6	40.8**
	Sludge-amended	range	147.7-256.3	201.7-310.4	361.3-399.0	224.6-296.1	
		means	181.6	257.1	379.0	248.9	70.2**
Zn	Control	range	9.4-15.1	8.8-18.1	8.7-14.7	6.3-12.9	
		means	11.4	11.8	10.6	8.4	2.4**
	Sludge-amended	range	177.4-307.3	214.8-334.1	203.9-253.3	129.5-200.1	
		means	237.8	264.8	227.0	154.0	41.2**
Cu	Control	range	0.68-0.69	0.68	0.67	0.68	
		means	0.68	0.68	0.67	0.68	n.s.
	Sludge-amended	range	16.0-23.5	14.9-20.0	15.0-19.7	6.8-8.9	
		means	19.5	17.7	17.9	7.7	4.2**

(continued)

TABLE 74. (continued)

Element[a]			Dried 1975			Dried 1974	
			Air-dried	$60^{o}C$	$110^{o}C$	$60^{o}C$	LSD
			ppm (dry weight)				
Ni	Control	range	1.6	1.6-2.4	1.6-2.1	1.5-1.9	
		means	1.6	2.0	1.9	1.7	n.s.
	Sludge-amended	range	7.3-8.4	6.8-8.9	6.7-9.7	4.7-5.8	
		means	7.7	7.8	7.9	5.3	1.5**
Cr	Control	range	bdl	bdl	bdl	bdl	
		means					
	Sludge-amended	range	1.4-2.0	1.6-1.8	1.8-2.3	0.62-1.1	
		means	1.6	1.6	2.0	0.76	0.44**
Cd	Control	range	0.42-0.63	0.42-0.73	0.51-0.72	0.35-0.85	
		means	0.50	0.52	0.59	0.49	n.s.
	Sludge-amended	range	9.7-12.8	8.8-11.8	9.6-12.6	6.6-7.5	
		means	11.0	10.8	11.1	7.0	1.7**

[a] Levels of Pb were below detectability in all samples.

[b] Samples were collected in 1974, but portions were not dried until 1975.

bdl Below detectable limit

n.s. Not significant

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

exception was P levels extracted with 2.5% CH_3COOH. Although the statistical analysis was not shown, 0.1 N HCl extracted significantly ($P \leq 0.01$) higher levels of all elements from both control and sludge-amended soil than did 2.5% CH_3COOH. The latter acid was a particularly ineffective extractant for Cr and Pb.

Effect of Incubation on the Extractability of Selected Elements--

Similarities and contrasts between 0.1 N HCl and 2.5% CH_3COOH extractable levels of elements from soil samples adjusted to different moisture contents and incubated at different temperatures may be seen from data presented in Tables 75 and 76. In both control and sludge-amended soil, 0.1 N HCl extractable P increased with increasingly greater moisture contents and these levels were not significantly affected by incubation temperatures (Table 75). Although the magnitudes were considerably different than amounts extracted with HCl, amounts of P extracted with 2.5% CH_3COOH were also increased by higher soil moisture contents when incubated at 4- and 20-°C (Table 76). But at the highest moisture content, higher incubation temperatures caused a decrease in 2.5% CH_3COOH extractable P, an effect which was not observed with HCl. Effects of soil moisture contents and incubation temperatures on levels of Fe and Mn extracted with either 0.1 N HCl or 2.5% CH_3COOH were similar on both control and sludge-amended soil. Both extractable Fe and Mn levels were increased by higher soil moisture contents, and at the highest moisture contents, higher incubation temperatures significantly increased extractable concentrations of both elements. Apparently moisture contents had less effect on 0.1 N HCl extractable Zn in soil from control plots than differences in incubation temperatures (Tables 75 and 76). At the two lower moisture contents of soil from control plots, the highest incubation temperature (30°C) caused a significant increase in 0.1 N HCl extractable Zn. On the contrary, no temperature effects were observed on 2.5% CH_3COOH extractable Zn concentrations in samples from control plots. At higher moisture levels, incubation temperatures did not significantly alter 0.1 N HCl extractable Zn levels in sludge-amended soil but did affect 2.5% CH_3COOH extractable concentrations. At the highest moisture level in sludge-amended soil, 2.5% CH_3COOH extractable Zn was significantly increased by incubation of samples at 30°C as compared to 20°C (Table 76). Incubation temperatures affected 0.1 N HCl extractable levels of Cu only in samples from control plots and 2.5% CH_3COOH extractable concentrations of Cu only in samples of sludge-amended soil. In control plot samples, 0.1 N HCl extractable Cu levels were highest when samples having the two highest moisture contents were incubated at 20°C. In samples from sludge-amended plots, 0.1 N HCl extractable Cu concentrations were increased by higher soil moisture contents, but differences in incubation temperatures did not affect levels. Levels of Cu extractable from control plot samples with 2.5% CH_3COOH tended to increase with higher soil moisture contents, but were not affected by differences in incubation temperatures. Only in sludge-amended soil did differences in incubation temperatures affect 2.5% CH_3COOH extractable levels of Cu. In sludge-amended soil incubated at the two lowest moisture contents, increasing incubation temperatures caused increases in 2.5% CH_3COOH extractable Cu levels; but at the highest moisture content, it caused lower extractable Cu levels. Concentrations of Ni extractable with 0.1 N HCl did not change in control soil incubated at different moisture contents, but were increased by higher soil moisture contents in sludge-amended soil incubated at 20- and 30-°C (Table 75). Nickel

TABLE 75. MEAN CONCENTRATIONS OF 0.1 N HCl EXTRACTABLE ELEMENTS IN BLOUNT SILT LOAM SOIL (0-15 cm DEPTH) REPLICATED CONTROL AND SLUDGE-AMENDED PLOTS AFTER INCUBATION AT DIFFERENT MOISTURE AND TEMPERATURE CONDITIONS.

Element	Temperature (°C)	Control				Sludge-amended			
		Moisture percent				Moisture percent			
		30	60	90	LSD	30	60	90	LSD
		ppm (dry weight)							
P	4	224.8	245.8	274.5	36.0*	1625.5	1924.0	2259.3	476.1**
	20	240.0	281.8	314.5	58.2**	1592.0	1888.0	2365.5	388.6**
	30	247.3	285.8	356.8	67.7*	1639.5	1861.5	2522.3	454.3**
Fe	4	213.3	237.3	273.0	44.1**	1476.2	1775.0	2031.7	324.1*
	20	230.3	299.3	847.5	261.3**	1557.7	1932.2	3152.7	466.9**
	30	218.0	251.0	2068.2	195.7**	1607.2	1788.2	4183.5	458.9**
	LSD		47.7**	220.1**				757.0**	
Mn	4	126.5	118.5	147.5	14.7**	345.7	411.0	457.7	60.6*
	20	148.0	156.2	614.5	165.4**	344.2	389.2	760.5	188.3**
	30	137.0	129.2	949.2	275.5**	341.5	352.2	1017.0	183.4**
	LSD		29.6**	239.9**				227.4**	
Zn	4	15.9	15.8	16.4		353.1	394.3	424.5	61.0**
	20	15.6	18.5	18.3		336.1	382.9	396.6	43.3*
	30	24.7	34.1	17.1	9.1**	327.2	349.7	389.7	46.1*
	LSD	5.4**	10.2**						
Cu	4	4.2	4.4	4.9		71.8	76.9	89.1	9.1**
	20	4.4	5.3	6.3	1.1*	70.3	81.4	87.6	6.6**
	30	4.1	4.5	5.8	0.9**	74.0	77.1	88.1	8.4**
	LSD		0.6*	0.8*					

(continued)

TABLE 75. (continued)

Element	Temperature (^{o}C)	Control				Sludge-amended			
		Moisture percent				Moisture percent			
		30	60	90	LSD	30	60	90	LSD
		ppm (dry weight)							
Ni	4	2.1	1.4	1.3		11.3	13.0	14.5	
	20	1.7	3.4	2.6		11.4	13.1	16.2	2.7**
	30	2.9	3.0	3.0		11.5	12.0	15.0	2.8**
	LSD	0.8*							
Cr	4	Below Detectable Limit				47.8	51.5	63.0	
	20					45.7	57.6	63.9	
	30					43.4	48.9	68.0	
Cd	4	0.7	0.5	0.8		16.4	17.9	20.2	2.7**
	20	0.6	0.5	0.8		16.0	17.9	18.3	1.8**
	30	0.7	0.6	0.6		16.7	17.7	18.2	
Pb	4	6.2	7.2	7.0		50.2	60.3	69.6	10.7*
	20	7.1	7.4	11.2	2.8**	50.8	59.3	72.5	9.2**
	30	7.0	6.7	12.1	2.0**	51.7	57.4	76.5	12.5**
	LSD			2.4**					

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 76. MEAN CONCENTRATIONS OF 2.5% CH_3COOH EXTRACTABLE ELEMENTS IN BLOUNT SILT LOAM SOIL (0-15 cm DEPTH) FROM REPLICATED CONTROL AND SLUDGE-AMENDED PLOTS AFTER INCUBATION AT DIFFERENT MOISTURE AND TEMPERATURE CONDITIONS.

Element[a/]	Temperature	Control Moisture percent 30	 60	 90	 LSD	Sludge-amended Moisture percent 30	 60	 90	 LSD
		ppm (dry weight)							
P	4	139.0	153.7	195.7	35.8*	313.5	387.5	508.5	124.8**
	20	158.5	182.7	187.2	17.5*	304.5	389.0	392.0	62.9*
	30	163.7	183.0	172.2		320.0	388.0	242.2	83.5**
	LSD			14.8*				164.2**	
Fe	4	12.0	15.0	16.3	1.5**	23.5	36.0	58.8	
	20	12.0	14.0	283.3	158.7**	17.3	22.0	678.5	192.2**
	30	11.8	13.5	1089.5	219.6**	15.0	18.5	1505.3	247.5**
	LSD			236.0**				383.0**	
Mn	4	66.0	48.5	73.0		163.0	177.3	223.5	43.4*
	20	52.3	50.5	526.7	161.1**	147.8	159.3	582.8	166.7**
	30	48.0	44.0	797.5	253.1**	132.5	144.0	947.3	314.3**
	LSD			212.9**				247.1**	
Zn	4	9.8	8.6	11.5		218.3	252.9	300.0	55.9**
	20	8.0	8.3	10.7	2.2*	216.4	250.6	291.4	47.4**
	30	9.3	8.9	10.2		214.8	247.6	306.0	35.0**
	LSD							11.2*	
Cu	4	0.6	0.7	0.8		11.7	13.8	17.3	1.7**
	20	0.5	0.8	0.9	0.3**	10.3	12.7	10.1	
	30	0.6	0.6	0.9		14.1	17.8	9.0	4.9**
	LSD					2.9**	2.2**	6.6**	

(continued)

TABLE 76. (continued)

Element[a]	Temperature	Control Moisture percent 30	 60	 90	LSD	Sludge-amended Moisture percent 30	 60	 90	LSD
		ppm (dry weight)							
Ni	4	Below Detectable Limit				6.3	7.3	8.3	1.4*
	20					5.5	7.2	9.4	2.6**
	30					6.3	7.3	9.5	2.4*
Cd	4	0.2	0.1	0.1		9.0	10.0	12.5	2.6**
	20	0.2	0.2	0.1	0.1*	8.4	9.7	9.9	
	30	0.2	0.2	bdl		9.9	9.9	8.7	0.9*
	LSD							2.8*	

[a] Chromium and Pb levels were below detectable limits in all combinations of conditions tested.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

was below detectable limits of 0.05 mg/kg in 2.5% CH_3COOH extracts of control soil whereas similar extracts of sludge-amended soil contained small but significantly higher Ni contents at all incubation temperatures for samples containing increasingly higher moisture levels. Incubation temperatures affected Ni levels only in 0.1 N HCl extracts of samples from control plots, incubated at the lowest moisture content. In these samples, 0.1 N HCl extractable nickel concentrations were increased by increasing incubation temperature from 20°C to 30°C (Table 75). Measureable amounts of Cr were present only in 0.1 N HCl extracts of incubated sludge-amended soil. Levels of Cr were not significantly affected by differences in soil moisture contents or incubation temperatures. Concentrations of Cd extractable with 0.1 N HCl from control samples did not change with differences in soil moisture levels or incubation temperatures. Where sludge-amended soil was incubated at 4- and 20-°C, amounts of Cd extracted with 0.1 N HCl were significantly increased by higher soil moisture contents. Levels of 2.5% CH_3COOH extractable Cd in control soil tended to decrease in samples incubated at higher soil moisture contents, although levels were significantly affected only in samples incubated at 20°C. Higher soil moisture contents resulted in higher levels of 2.5% CH_3COOH extractable Cd in sludge-amended soil incubated at 4°C, but caused lower extractable levels in similar samples incubated at 30°C. At the highest soil moisture content, increasing soil incubation temperatures resulted in significant decreases of 2.5% CH_3COOH extractable Cd in sludge-amended soil (Table 76). These latter findings, with regard to Cd, were similar to those discussed above for P and Cu. Lead was below detectable levels of 0.2 mg/kg in all 2.5% CH_3COOH extracts, but present in measureable amounts in all 0.1 N HCl extracts. Amounts of Pb extracted with 0.1 N HCl were found to increase with higher soil moisture contents where control samples were incubated at 20- and 30-°C and at all incubation temperatures where samples were from sludge-amended plots. Also, levels of 0.1 N HCl extractable Pb were increased by increasing temperatures in control soil adjusted to the highest moisture content, but not in sludge-amended soil.

Comparisons were made between 0.1 N HCl extractable levels in soil samples dried at 60°C in 1974 (Table 73) and split samples adjusted to moisture contents equivalent to 30 percent of the total water holding capacity and incubated for 30 days at 4°C (Table 75). All incubated samples were analyzed without drying. Control samples dried at 60°C had significantly lower 0.1 N HCl extractable levels of P and higher levels of Fe and Mn than samples incubated at relatively low temperatures and moisture contents ($P \leq 0.01$). From a similar comparison of results for sludge-amended soil, it was observed that drying samples at 60°C reduced amounts of P, Zn, and Cd extractable with 0.1 N HCl as compared to amounts found in samples incubated at 4°C and lowest moisture contents ($P \leq 0.01$). Drying samples at 60°C caused significant decreases in amounts of P and increases in amounts of Mn and Cd extracted with 2.5% CH_3COOH from control soil when compared to samples incubated at low temperatures and moisture contents ($P \leq 0.01$). Also, since Ni was present in detectable amounts (1.7 mg/kg) in control soil samples dried at 60°C, but not detectable in incubated samples, it appears safe to assume that drying increased CH_3COOH extractability of the element. Further comparison of 2.5% CH_4COOH extractable levels of selected elements from sludge-amended soil showed that drying samples at 60°C decreased extractable levels of Zn and Cu, but increased extractable levels of Fe and Mn ($P \leq 0.01$).

In contrast to results from control soil, 2.5% CH_3COOH extractable Ni levels were unchanged by drying sludge-amended soil. However, detectable amounts of Cr (0.8 mg/kg) were present in CH_3COOH extracts of sludge-amended soil dried at 60°C, but not in incubated samples. Thus, like Ni in control soil, it appeared that 2.5% CH_3COOH extractable Cr was increased in sludge-amended soil by drying.

SECTION 7

ANIMAL STUDIES

SELECTED CHEMICAL ELEMENTS IN TISSUES OF PHEASANTS FED CORN GRAIN PRODUCED ON SEWAGE SLUDGE-AMENDED SOIL

General Description

Little is known about the absorption of heavy metal constituents from ordinary foods or various routes of metal excretion by animals (Underwood, 1971). In the past, nearly all of the feeding studies were conducted by adding soluble metal salts to rations at levels considerably above those obtainable in healthy plant materials. Often the intent was to produce gross pathological changes in test animals within a few days or weeks after initiation of studies. Generalization of results from single-ion dose-response studies to predict physiological changes in animals ingesting various amounts of heavy metals from diets of natural food materials may not be acceptable. Feed-grain plants maintain a balance within certain limits between chemical element species which has frequently been ignored by investigators conducting dose-response feeding studies. Furthermore, trace elements ingested by animals as constituents of plant materials may not be as available as those added to feed rations as soluble inorganic compounds. Lassiter, et al. (1972) reported that livers, kidneys, and duodenums of rats receiving radio-manganese as a chloride salt contain three times more ^{54}Mn than such organs from rats fed forages with radio-active Mn incorporated by plant growth processes. When supplied to protect chicks against exudative diathesis, Bragg and Seier (1974) found that Se contained in rapeseed meal at 0.95 mg/kg was only 61.3 percent available as compared to similar concentrations added to rations as Na_2SeO_3. Results from other studies suggest that Zn and Mn may be associated with the lignin-cellulose matrix in plants (Bremner, 1970). Lignin is highly resistant to decomposition in animal digestive tracts and protects associated cellulose from decomposition. Consequently, metals complexed with these compounds may not be available for absorption to the same extent as those provided as soluble salts. On the other hand, metals contained in young forage plant tissues, characterized by low-level lignin contents, may be as readily absorbed by ruminant animals as those supplied as soluble salts. Neatherly, (1972), found that ^{65}Zn incorporated by growth processes into 19 or 33 day old corn plants was as readily absorbed by calves fed a Zn-deficient diet as when the metal was supplied as $^{65}ZnCl_2$ via capsule.

Toward assessing the potential health hazard to animals associated with the feeding of corn (Zea mays L.) grain produced by the use of sewage sludge as a fertilizer material, a study was initiated in the winter of 1973 using pheasants (Phasianus colchicus) as test animals. Pheasants were a logical choice because their range is coextensive with a considerable portion of the corn-belt states, and during the winter months corn grain is the staple item of their diet (Labisky and Anderson, 1973). It was also anticipated that results of the study would be directly applicable to other birds such as Bobwhite quail (Colinus virginianus). The preservation of endemic fauna and its use as a human food source will be a major concern wherever schemes are adopted for utilizing waste materials as fertilizers and soil amendments. Results reported here will be of special importance to those who have the responsibility for assessing environmental impacts of such schemes.

During October, 1973, corn grain for the pheasant feeding study was harvested from replicated, digested sewage sludge-treated plots where rates of application were 0, ¼-maximum, ½-maximum, and maximum amounts possible to apply by furrow irrigation during the growing season. This continuous corn study was described in detail in Section II of this report. Total amounts of sludge applied during the six years (1968 through 1973) on each maximum-treated plot were equivalent to 369 mt/ha (dry weight). Harvested grain was dried to a moisture content of 8 to 9 percent dry weight and stored in plastic garbage containers for use in the pheasant feeding study. Concentrations of selected chemical elements were determined in 4 samples of corn grain from quantities of grain representative of the four respective sludge treatments mentioned above. Methods of analyses were essentially those routinely employed in our laboratory, including both atomic absorption and emission techniques for metals. These methods were discussed in Section I of this report.

On December 3, 1973, 35 females were randomly selected for the feeding study from a pen of several hundred pheasants. All the pheasants were hatched during early June, 1973, and maintained at the Illinois Department of Conservation Game Farm, Yorkville, Illinois, on a diet of whole oats, where corn grain was supplied occasionally. The 35 birds selected were transported to the University of Illinois South Farm where they were weighed, supplied with a numbered leg band, and placed in cages. Four birds were placed in each of eight cages, with an additional cage used to maintain three additional birds. Two cages of four birds each were randomly designated to receive corn grain harvested from plots where soil had been amended with sludge at one of the four loading rates discussed above. Cages consisted of wooden frames 1.5 m long, 1.5 m wide, and 1.8 m high, enclosed with 2.54 x 5.08 cm galvanized hardware cloth. All cages were located in an open area enclosed by a woven wire fence only. Thus, birds were fully exposed to the harsh winter conditions characteristic of the months of December, January, February, and March in the corn-belt states. However, on January 8 about 2/5 of the surface area of each cage floor was covered with 0.6 cm thick masonite board. Installation of the board reduced the incidence of frostbite suffered by the feet of pheasants exposed to the hardware cloth floors. Frostbite was especially severe because hardware cloth floors were 0.5 m above the ground level.

From December 3rd to December 19th the birds were fed commercially produced shelled corn, free choice. On December 19th, 600 grams of corn grain harvested from control plots or plots amended with a particular sludge loading rate were placed in plastic cage feeders. Every two or three days corn grain remaining in each cage was removed and weighed to obtain an estimate of consumption before another increment of 600 grams was restored to the feeders. Initially, pheasants were provided with a medium granite grit. This was replaced on January 7 for the remainder of the feeding period by equal parts by weight of crushed limestone and granite grit, 2 to 6 mm in diameter. Distilled water was supplied to the birds in plastic containers, but no provisions were made to keep it from freezing.

Weights of individual birds were recorded initially on December 3, again on December 11, December 18, December 31, January 28, February 25, and for the last time when the feeding study was terminated. On March 28 the birds were bled by decapitation before transferring whole birds to the laboratory for dissection. Dissection processes included the removal of breast muscle from the most forward point of the keel bones and extending rearward about 2.54 cm and laterally to rib cages for the entire depth of tissues. Livers and kidneys were removed and blotted with Kimwipe towels to remove excess blood and fat tissues. Duodenal tissues were removed and placed on dry, clean sheets of plexiglass and opened with longitudinal incisions. They were then pressed flat against the plexiglass sheet, irrigated with 0.95 percent NaCl solution, blotted dry, and weighed. After weighing, the various tissue samples were placed in acid-cleaned snap-cap bottles and stored in a freezer.

Plastic cafeteria trays were placed in the corner of cages on March 13 to collect bird droppings. Droppings were collected daily for a period of eight days, composited by cage, oven-dried, and placed in acid-cleaned snap-cap bottles until prepared for analyses.

Procedures used for the various chemical analyses of limestone and granite grit and feces samples were essentially those used routinely in our laboratory for determining total concentration levels of chemical elements in soils.

After defrosting, tissue samples were dried to a constant weight at 60°C. Dried breast muscle samples were ground in a Wiley mill from which 2 g subsamples were used for analyses. Whole, dried samples of duodenal tissues and kidneys were used for analyses.

Breast muscle, kidney, and duodenal tissue samples were digested in 10 ml of concentrated nitric acid at 90°C until the acid ceased fuming (approximately six hours). After heating to dryness, samples were digested in 10 ml of 30 percent peroxide at 90°C for about three hours or until a clear liquid was attained. Clear digestates of samples were brought to dryness on a hot plate. Residues of digested tissue samples were then dissolved in 10 ml of 0.5 N HNO_3 for determinations of P, Mg, Ca, K, Na, Zn, Cd, Ni, Cu, Mn, and Fe concentration levels in tissues by spectrophotometric techniques. Phosphorus was determined by a molybdenum blue method using "Bray" reductant as described by Peterson and Corey (1966).

Digestion of liver and leg muscle tissues did not yield clear liquid digestates by the above procedure because of their content of fat. Therefore, prior to the digestion operation, fat was removed from liver and leg muscle samples by refluxing with ethyl ether for four hours in a Sohxlet apparatus. Several samples ground in a Wiley mill were individually wrapped in filter paper and placed together in the Sohxlet apparatus. After refluxing, samples were evaporated to dryness, weighed, and prepared for analyses in the same way as described for other bird tissues.

Leg bones (femur and tibia) were first autoclaved to remove extraneous tissues, then successively extracted with 99 percent ethyl alcohol and ethyl ether. Bones were then dried at 60°C and ground in a Wiley mill prior to weighing 0.25 gram samples for digestion and analyses as described above for other tissues.

Discussion of Results

Concentrations of Selected Elements in Grain and Grit--

Concentration levels of selected chemical elements in corn grain fed to pheasants are presented in Table 77. Values are mean contents as found from analyses of grain batches representing each of the four sludge application rates. It is noteworthy that Cd contents were increased about 10-fold and Zn and Ni about 2-fold in corn grain from maximum-sludge-treated as compared to contents in grain from control plots. Some heavy metal contents of corn grain harvested from maximum-sludge-treated plots were lower in 1973 than in grain harvested from the same treated plots in other years. Nevertheless, mean concentrations of Zn, Cd, and Ni were considerably higher in grain from maximum-sludge-treated plots than expected where sludge is applied at rates to provide supplementary nitrogen fertility. Cadmium contents of 1973 grain from maximum-sludge-treated soils were also somewhat above the upper range of expected concentrations in corn grain as reported by Fleischer, et al. (1974). From a review of the literature they concluded that Cd contents of corn, rice, wheat, and oat grain may range from 0.1 to 0.5 ppm when grown in environments presumably having normal Cd levels.

Concentrations of several chemical elements in limestone and granite used as a source of grit are also shown in Table 77. Of the several chemical elements only Zn, K, and P in limestone, and Cd, Zn, and P in granite were present at levels lower than those in corn grain from maximum-sludge-treated plots.

In view of the fact that a number of researchers have reported that Zn ameliorates effects of Cd on certain vascular tissues and growth of rats (Banis, et al., 1969; Ferm and Carpenter, 1967; Gunn, et al., 1961; and Parizek, 1957) it is of some significance that Zn to Cd concentration ratios decreased from 482 in grain from control plots to 102 in grain harvested from the maximum-sludge-treated plots. In this respect, Zn to Cd ratios of contents in locally purchased limestone and granite grit materials were 47 and 256, respectively.

TABLE 77. SELECTED CHEMICAL ELEMENT CONCENTRATION LEVELS IN 1973 CORN GRAIN HARVESTED FROM BLOUNT SILT LOAM PLOTS WHICH WERE TREATED WITH DIGESTED SLUDGE DURING SIX GROWING SEASONS BY FURROW IRRIGATION, AND IN LIMESTONE AND GRANITE PROVIDED AS A SOURCE OF NUTRIENTS AND GRIT TO PHEASANTS.[a/]

Total sludge treatment mt/ha (d.w.)	Zn	Cd	Ni	Cu	Mn	Fe	Ca	Na	Mg	K	P
					Corn grain						
	ppm								%		
0	28.92	0.06	0.69	1.89	7.60	14.26	19.07	3.81	0.102	0.385	0.292
92.2	38.41	0.17	0.90	2.21	6.75	14.65	20.00	3.72	0.121	0.427	0.301
184.3	47.56	0.33	1.00	2.08	6.81	14.93	18.17	4.70	0.124	0.450	0.317
368.6	59.99	0.59	1.44	1.61	6.61	16.72	16.42	4.18	0.124	0.442	0.337
LSD	2.74**	0.10**	0.14**	--	0.30**	--	--	--	--	0.038*	0.009**
					Grit materials						
	ppm				%						
Limestone	36.31	0.77	3.19	11.94	0.120	0.34	33.47	0.25	0.32	0.14	0.024
	ppm					%					
Granite	56.44	0.22	2.03	9.73	82.10	0.38	0.78	4.12	0.18	2.52	0.022

[a/] Values are dry weight means of results from four replicated determinations for elements in corn grain and three replicated determinations for elements in limestone and granite.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Grain Consumption and Weight Changes--

Percent change in bird weights and rate of grain consumption are presented in Figure 110 as a general indicator of health of pheasants fed grain from different sources. Initial percent change in weight was based on the weight of the pheasants on December 3 when they were assigned to specific cages. Initial weight losses were anticipated as a result of subjecting the birds to new and different environmental conditions, especially with respect to cage floors situated above ground level. Weight losses during the first week after being caged were not regained until the latter part of January, except by those birds fed grain from ½-maximum and maximum-sludge-treated plots. After pheasants were given grain from experimental plots they continued to increase their rate of grain consumption until the latter part of January when the rate became relatively constant. The rate remained rather constant until the latter part of February. With the passing of the period of extremely low temperature in February it again increased and was reflected by increased weight gains of birds in all groups. Because of large variations between individual birds or cages of birds, rates of grain consumption and changes in weight were not statistically different regardless of grain source. Nevertheless, it is of some significance that no statistically significant differences were found in the results presented in Figure 110, as will become evident in the following discussion regarding Cd contents in pheasant tissues.

Concentrations of Selected Elements in Pheasant Tissues--

Results presented in Table 78 show that only Cd contents of pheasant duodenal, liver, and kidney tissues were significantly increased as a result of higher concentration levels of several elements in grain. Increased amounts of Cd in duodenal tissues were directly proportional to increased amounts in corn grain reflecting sludge treatments. That is, 10-fold increases in Cd concentrations in corn grain, as caused by maximum sludge application rates, were reflected by similar increased amounts in pheasant duodenal tissues. On the other hand, Cd contents of livers and kidneys of birds fed grain from maximum-sludge-treated plots were only about 3-fold greater than those found in the same kind of tissues from birds fed grain from control plots.

Amounts of Cd in liver tissues were reported on a fat-free basis. Fat contents of liver ranged from 17.0 to 22.7 percent dry weight and did not differ by source of grain. Thus, Cd contents in liver as reported in Table 78 were greater than actual amounts in whole liver samples. Extracted fat was not analyzed for metals but amounts contained in it were assumed to be relatively small. Cadmium levels in fat-free livers of pheasants fed grain from maximum-sludge-treated plots were similar to concentrations in livers of pheasants from the same Illinois State Game Farm, but fed for an eight-week period on different diets. Anderson and Labisky (1974) found wet weight contents of 0.63 ± 0.04-, 0.73 ± 0.09-, and 0.43 ± 0.02-mg Cd/kg in liver tissues of pheasants fed a commercial flight and maintenance chow, normal corn, and high-lysine corn, respectively. Moisture contents of 72 percent for liver tissue (Skelton, 1927) were used to convert wet weight Cd concentration in the livers of pheasants fed normal corn grain to a dry weight basis. Derived dry weight contents of 2.25-, 2.61-, and 1.54-mg/kg are comparable to mean Cd contents of 1.99 ppm in livers of pheasants fed corn grain from maximum-sludge-amended plots (Table 78).

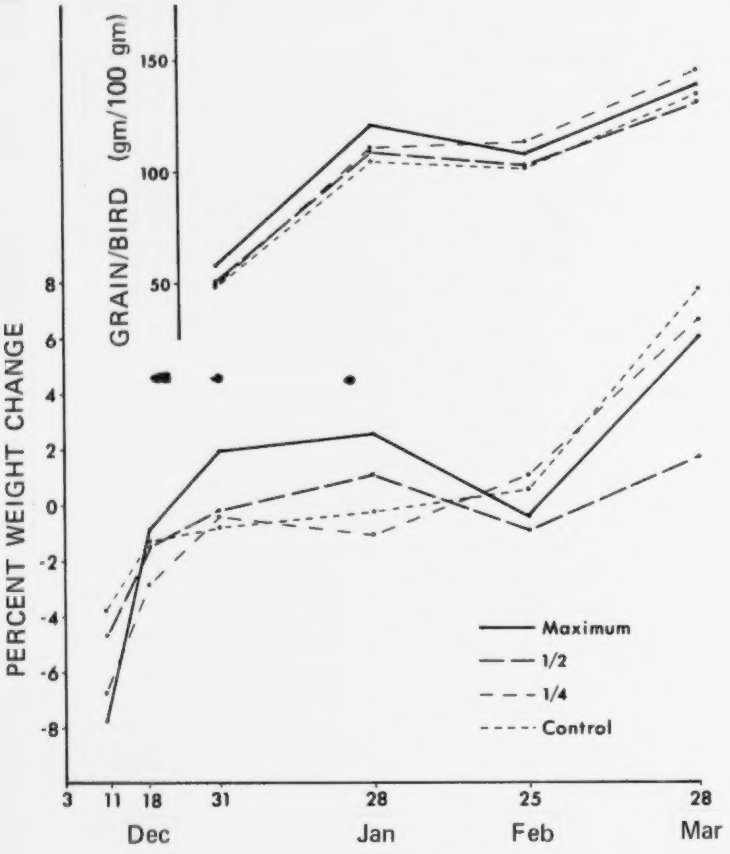

Figure 110. Changes during approximately monthly intervals in grain consumption and weights of pheasants fed 1973 corn grain from plots which received 0 (control), 92.2 (1/4-maximum), 184.3 (1/2-maximum), and 368.6 (maximum) mt/ha of sludge applied in approximately annual equal increments over a 6-year period.

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Fig 110-553

TABLE 78. MEAN CONCENTRATIONS OF SELECTED CHEMICAL ELEMENTS IN SELECTED TISSUES OF PHEASANTS FED ONLY CORN GRAIN FROM CONTROL AND SLUDGE-TREATED PLOTS DURING THE PERIOD DECEMBER 19, 1973 TO MARCH 28, 1974.

Total sludge treatment mt/ha (d.w.)	Zn	Cd[a]	Ni[a]	Cu	Mn	Fe	Ca	Na	Mg	K	P
	ppm dry wt.						% dry wt.				
					Duodenum						
0	78.6	0.08	<1.69	6.83	3.20	138	0.017	--	0.062	0.79	0.88
92.2	90.7	0.26	<1.69	7.25	2.96	192	0.009	--	0.075	0.91	1.02
184.3	88.9	0.63	<1.69	7.60	2.74	157	0.011	--	0.072	0.93	0.97
368.6	95.3	0.80	<1.69	7.13	2.79	219	0.010	--	0.088	0.95	0.97
LSD		0.42**									
					Liver (fat free)						
0	90.0	0.66	<1.03	16.6	9.21	396	0.009	0.41	0.067	1.00	1.24
92.2	90.7	1.24	<1.03	17.6	9.00	474	0.009	0.42	0.066	1.03	1.23
184.3	87.8	1.72	<1.03	17.1	8.52	457	0.010	0.41	0.065	1.02	1.23
368.6	87.1	1.99	<1.03	16.3	7.98	453	0.008	0.42	0.060	0.99	1.19
LSD		0.84**									
					Kidney						
0	60.4	2.84	<1.28	11.6	5.46	230	0.020	0.52	0.056	1.09	1.09
92.2	69.7	5.57	<1.28	13.8	6.14	272	0.021	0.58	0.062	1.19	1.22
184.3	75.7	8.66	<1.28	14.3	6.10	316	0.021	0.62	0.067	1.24	1.27
368.6	70.3	9.41	<1.28	15.8	6.00	268	0.020	0.58	0.051	1.19	1.19
LSD		3.29**									
					Breast muscle						
0	18.5	<0.125	<1.25	3.51	0.55	31.0	0.004	0.08	0.109	1.46	0.96
92.2	18.4	<0.125	<1.25	3.33	0.65	35.3	0.004	0.09	0.106	1.40	0.94
184.3	19.1	<0.125	<1.25	3.48	0.51	38.5	0.004	0.08	0.110	1.46	0.99
368.6	19.0	<0.125	<1.25	3.23	0.51	33.1	0.004	0.09	0.110	1.50	1.00
					Leg muscle (fat free)						
0	64.9	0.02	<0.25	4.66	0.93	58.0	0.028	0.31	0.092	1.55	1.33
92.2	67.9	0.03	<0.25	4.73	0.86	59.3	0.022	0.30	0.098	1.62	1.39
184.3	70.3	0.05	<0.25	4.79	0.86	59.8	0.033	0.29	0.095	1.64	1.35
368.6	71.5	0.05	<0.25	4.29	0.87	59.8	0.026	0.30	0.096	1.65	1.37
					Leg bone (femur & tibia)						
0	226	0.10	<1.00	1.34	7.77	36.5	23.4	0.50	0.460	0.04	20.5
92.2	226	0.06	<1.00	1.68	7.72	36.0	24.3	0.50	0.556	0.04	21.8
184.3	226	0.11	<1.00	2.02	7.33	39.0	23.2	0.48	0.469	0.04	20.2
368.6	229	0.06	<1.00	1.55	7.38	34.0	22.4	0.49	0.580	0.05	19.3

a/ Detectable limits varied for Cd and Ni because sample size ranged from 0.5 g for duodenal tissue to 2.5 g for liver tissue and because dilution factors differed for different tissues.

** Significant at the 0.01 level.

Fleischer, et al. (1974) found wet weight concentrations of 0.57-, 0.55-, and 2.04-mg Cd/kg in the livers of starling, robin and ruffed grouse, respectively, had been reported in the literature. On a dry weight basis the respective values were 2.04-, 1.94-, and 7.29-mg Cd/kg. Since the ages of these birds were not reported the Cd levels are not directly comparable to those found in pheasant livers from our study. They do, however, indicate that birds exposed to normal dietary levels of metals may often have Cd concentrations in their livers as high as those found in pheasants fed for 100 days on corn grain from sludge-treated plots.

Cadmium levels in pheasant kidneys from birds fed grain from sludge-treated plots are comparable to those in kidneys of pheasants captured from normal habitats. Anderson and Stewart (1969) found wet weight Cd concentrations of 1.20-, 1.46-, and 0.89-mg Cd/kg in kidneys of seven month old hen pheasants captured from wild populations at three different location in Illinois. Assuming moisture contents of kidney to be about 78 percent (Skelton, 1927), then dry weight concentrations were 5.45-, 6.64-, and 4.05-mg Cd/kg. The magnitude of these Cd levels is not too dissimilar from the 5.57 to 9.41 mg/kg of Cd found in kidneys of hen pheasants which were two months older than those analyzed by Anderson and Stewart (1969).

Metal contents of breast muscle tissues were, in general, lower than those found in leg muscle tissues. This finding was in agreement with that of Anderson and Stewart (1970). Since the low Cd concentration levels in leg muscle did not differ significantly with treatment it seems unlikely that levels below the detection limits of the procedure used to analyze breast muscle were affected by levels in corn grain (Table 78). Like muscle tissues the small differences in metal contents of grain were not reflected in the chemical composition of leg bones.

It is of interest that the 2-fold increase in Zn and Ni concentration levels in corn grain resulting from the maximum application rate of sludge was not reflected by an increased deposition of these metals in pheasant tissues. Although not significant, Cu concentrations in kidney tissues showed a marked trend toward higher levels where birds were fed grain produced on plots fertilized with higher levels of sludge. However, Cu contents of grain were not increased by sludge applications, and thus, if this trend toward enhanced Cu concentrations in kidney tissue has any meaning, the explanation is not obvious.

Levels of each element in the several bird tissues were correlated with concentrations of each of the other elements in the same tissues (Table 78). Only a few correlations pertaining to Cd and Zn in tissues of birds fed grain from maximum-sludge-treated plots were statistically significant. In duodenal tissues, positive correlations were found between Cd and Fe and between Zn and Cu contents ($P<0.05$). In liver tissues, concentrations of Cd were not correlated with those of any other element, but Zn concentrations were positively correlated with P contents ($P<0.01$). The lack of significant correlation between levels of Cd and other heavy metals in animal liver is contrary to the findings of others. For instance, Mills (1974) concluded from an analysis of 68 observations that elevated Cd levels were associated with elevated Zn and depressed Cu levels in animal liver. Relative to amounts of metals normally supplied as soluble salts in animal rations during feeding studies, perhaps metal levels incorporated into grain by natural biological processes were too low to cause the same kinds of marked interaction effects. Again in kidney tissues concentrations of Cd were not correlated with those of any other element, but Zn contents were positively correlated with Mn ($P<0.05$), P ($P<0.05$), and Na ($P<0.01$). In breast muscle tissues, concentrations of Cd were below detectable limits and Zn contents were not correlated with concentrations of any other element. Concentrations of Zn in leg muscle tissues were positively correlated with Fe ($P<0.05$), Ca ($P<0.01$) and Cu ($P<0.01$) and negatively correlated with Mg ($P<0.05$) contents in the same tissues. No significant correlations were found between Cd concentrations and levels of other elements in leg muscle tissues. In leg bone samples, Zn and Mn concentrations were positively correlated ($P<0.01$) and was the only one observed between concentrations of elements. Although levels are not shown in Table 78, Pb contents were determined in leg bones and were found to be negatively correlated with Cd contents ($P<0.05$).

Concentrations of Selected Elements in Pheasant Feces--

Data are shown in Table 79 for percent ash and the several chemical element concentrations in composite samples of pheasant feces. Increased excretion of both Zn and Cd appeared to be associated with the increased levels in corn grain. Except in the feces of birds fed grain from control plots, the Zn to Cd ratio values were greater in feces than in corn grain. While it is tempting to attribute all the differences between ratios of Zn to Cd contents in feces as compared to the same ratios in corn grain to a greater relative deposition of Cd in bird tissues, the situation was too complex to permit such an interpretation. Relative availabilities of Zn and Cd in grit were unknown, as well as amounts consumed from this source by the birds.

Smaller amounts of K excreted by birds fed corn grain from plots amended with 184.3 mt/ha were considered to be an artifact because the Na and ash contents were also low. The material had perhaps been subjected to leaching conditions causing losses of more soluble constituents before samples were collected.

Excretion of other metals did not appear to be affected by source of grain. Concentrations of Ni and Cu in the feces of birds fed corn grain from sludge-treated plots were always lower than in parallel samples from birds on control grain. The insignificant trend for an accumulation of Cu in kidney tissue, mentioned above, might have been considered more meaningful in light of these results if contents of Ni in bird tissues had been similarly associated with differences in grain sources. Any relationship between grain source and Cu and Ni levels in feces was probably obscured by amounts ingested as constituents of grit materials.

Pheasants were provided with grit materials because ample experimental evidence indicated the need for grit when poultry was fed whole grain and course feed (Schaible, 1970). Lippincott (1946) pointed out that gastric juices were incapable of digesting cellulose walls of grains and did not act until grains were reduced by the gizzard to a more or less homogeneous pulp.

TABLE 79. SELECTED CHEMICAL ELEMENT CONCENTRATION LEVELS IN COMPOSITE SAMPLES OF PHEASANT FECES COLLECTED DAILY FROM MARCH 13 THROUGH MARCH 21, 1974, FROM CAGES OF BIRDS FED CORN GRAIN FROM CONTROL AND SLUDGE-TREATED PLOTS.

Total sludge treatment mt/ha (d.w.)	Zn	Cd	Ni	Cu	Mn	Fe	Mg	Ca	K	Na	P	Ash
	ppm						%					
0	145	0.39	5.26	16.48	114	896	0.67	1.41	1.22	0.21	1.51	15.4
92.2	214	0.75	2.21	9.65	86	614	0.59	0.78	1.31	0.11	1.76	12.3
184.3	302	1.41	1.80	7.17	93	548	0.55	1.02	0.89	0.07	1.57	10.7
368.6	380	1.82	1.72	7.57	142	854	0.52	1.64	1:49	0.09	1.94	15.0
LSD	130*	0.45**	1.73*	5.59**					0.31*			

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

If the birds had been deprived of grit, the availability of trace elements contained in whole corn grain for absorption and deposition in bird tissues might have been underestimated. Limestone grit used in this study was the same as that used on local agricultural lands to adjust soil pH to optimum levels for maintaining soil productivity. Thus, equivalent materials are readily available on soil surfaces to foraging wild pheasants. Scott and Heuser (1957) found that growing turkeys and laying hens appear to be able to adjust Ca intake according to their needs. In the absence of more specific information we assumed pheasants also posses the facility. Because corn grain contains only small quantities of Ca, and it was confirmed in Ca-deficient animals that the deficiency caused an increase absorption of Cd (Piscator and Larson, 1974), it was decided that limestone grit would be provided for the birds. Even though locally purchased limestone grit contained a mean Cd concentration of 0.77 mg/kg, which was higher than the highest level found in corn grain, to have withheld this source of Ca from the birds would have compromised the results of the study for those interested in practical aspects of trace element cycling in natural environments.

Accumulation of Grain-Cd in Pheasant Tissues--

Supplying the birds with grit did not preclude an assessment of amounts of metals accumulated in pheasants which were attributable to difference in grain source. However, since Cd was the only element for which concentrations in bird tissues were affected with different sources of grain, it was the only metal considered for estimating accumulations due to sludge treatments. To estimate proportional amounts accumulated in birds to amounts ingested as a constituent of grain, the average total amount of Cd in pheasant tissues and average total amounts of the metal consumed in corn grain during the 100-day study was calculated. Dry weights of tissues in which Cd accumulated and results of calculations are exhibited in Table 80. Amounts of Cd in bird tissue due to differences in grain contents of the metal were estimated by subtracting total Cd accumulated in tissues of birds fed grain from control plots from average amounts in similar tissues of birds fed grain from other sources. After subtracting, the remainders for total amounts of Cd in duodenum, liver, and kidney were summed according to birds fed grain from a particular source. The total amounts of Cd in the 3 tissues were assumed to be total amounts retained by the birds as a result of higher levels in grain. Accordingly, it was estimated that total amounts of the excess Cd in corn grain due to ¼-maximum, ½-maximum, and maximum-sludge-treatments that was retained by the birds were 6.81-, 9.83-, and 14.13-μg, respectively. In a similar manner total amounts of ingested Cd attributable to sludge treatments were obtained by subtracting average total amounts ingested by birds fed control grain from total amounts ingested by birds fed grain from other sources. Total amounts of Cd ingested in excess of amounts in control grain were estimated to have been 356-, 950-, and 2138-μg by birds fed grain from ¼-maximum, ½-maximum and maximum-sludge-treated plots, respectively. Thus, pheasants respectively retained an estimated 1.49-, 1.03, and 0.66-percent of the excess Cd in grain due to ¼-maximum, ½-maximum and maximum-sludge-treatments.

TABLE 80. CALCULATED TOTAL Cd DEPOSITED IN PHEASANT TISSUES AND TOTAL Cd INGESTED AS A CONSTITUENT OF CORN GRAIN DURING THE 100-DAY FEEDING STUDY.

Sludge treatment rate	Tissue	Ave. dry weight[a]	Ave. total Cd[b]
		--------g------	----µg-------
0	Duodenum	0.615	0.05
¼-max	Duodenum	0.655	0.17
½-max	Duodenum	0.579	0.36
Max	Duodenum	0.760	0.60
0	Liver	5.168	3.41
¼-max	Liver	5.869	7.28
½-max	Liver	4.829	8.31
Max	Liver	5.591	11.13
0	Kidney	0.744	2.11
¼-max	Kidney	0.885	4.93
½-max	Kidney	0.777	6.73
Max	Kidney	0.847	7.97
0	Corn grain	3,446	214
¼-max	Corn grain	3,848	670
½-max	Corn grain	3,513	1,164
Max	Corn grain	3,980	2,352

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[a] Pheasant tissue or grain consumed by pheasants.

[b] Average total Cd deposited in pheasant tissues was obtained by multiplying average dry weights by their respective average concentrations in Table 78. Average total Cd ingested as a constituent of grain was calculated by multiplying average grain consumption by average Cd concentration (Table 77).

Deposition of lower amounts of Cd in pheasant tissues when relatively higher amounts are ingested as constituents of grain was similar to the decreasing efficiency of absorption of Se at higher concentrations reported by others. Investigating Se deposition in tissues of hens fed rations containing different added levels of the element, Arnold, et al. (1973) and Scott and Thompson (1971) found higher levels in kidney, liver, heart, and thigh muscle tissue, by order of listing. In all organs efficiency of deposition was higher at relatively low dietary levels (0.2 to 0.3 mg/kg in rations). Apparently Cd and Se have a predilection for the same tissues and exhibit similarities in the way they are absorbed and deposited in organs of birds. Unfortunately, pheasant heart tissues were not analyzed during our study, and Cd concentrations, like those of Se, may be enhanced in such tissues when diets contain relatively high levels of the metal. But regardless of whether or not Cd levels were significantly increased in heart muscle, decreased efficiency of deposition with higher contents in grain was shown. The fact that pheasants captured from wild populations had Cd concentrations in liver and kidney which were comparable to the highest levels observed in this feeding study may have been due partially to more efficient absorption and deposition of low dietary levels.

It appears that the amount of Cd deposited in duodenal tissue is a linear response to amounts of Cd ingested as a constituent of corn, but not for liver and kidney tissues. For the latter two tissues, smaller proportional changes of Cd concentrations in bird tissues at higher as compared to lower levels of the metal in diets indicated a logarithmic relationship. Thus, the expression $y = a + b \log x$, where y is the amount of Cd deposited in tissues and x is the amount of Cd ingested as a constituent of grain, was used to fit a line through the data for liver and kidney as plotted in Figure 111. The data as plotted, are total Cd accumulated in bird tissues as a result of excess total ingested Cd in corn grain caused by the various sludge application rates. These data were obtained by appropriately subtracting amounts of Cd in tissues of birds fed control grain and amounts supplied as a constituent of control grain, as was discussed previously. Logarithmic equations provide a high degree of predictability as indicated by the correlation coefficients shown in Figure 111. The linear equation for total amounts of Cd in duodenal tissues resulted in a high degree of predictability ($r = 0.99$) of grain-Cd absorption.

The highest level of Cd in corn grain that we have observed was 1.1 mg/kg in 1972, on maximum-sludge-treated plots. Assuming a concentration of 1.1 mg/kg of Cd in grain, along with the assumption that pheasants would have consumed 3,980 g of grain in 100 days (Table 80, maximum-sludge-treatment), the total amount of Cd ingested in excess of birds on control grain would have been 4164 μg. Substituting this amount of excess grain Cd as the value "x" in the regression equations (Figure 111) predicts total Cd accumulations of 7.27 μg in kidney, 9.13 μg in liver, and 1.04 μg in duodenal tissues. When the amount accumulated in individual tissues were summed, total Cd retained in a particular bird would have been 17.44 μg. This translates into a retention of only 0.42 percent of the total amount of excess Cd ingested by

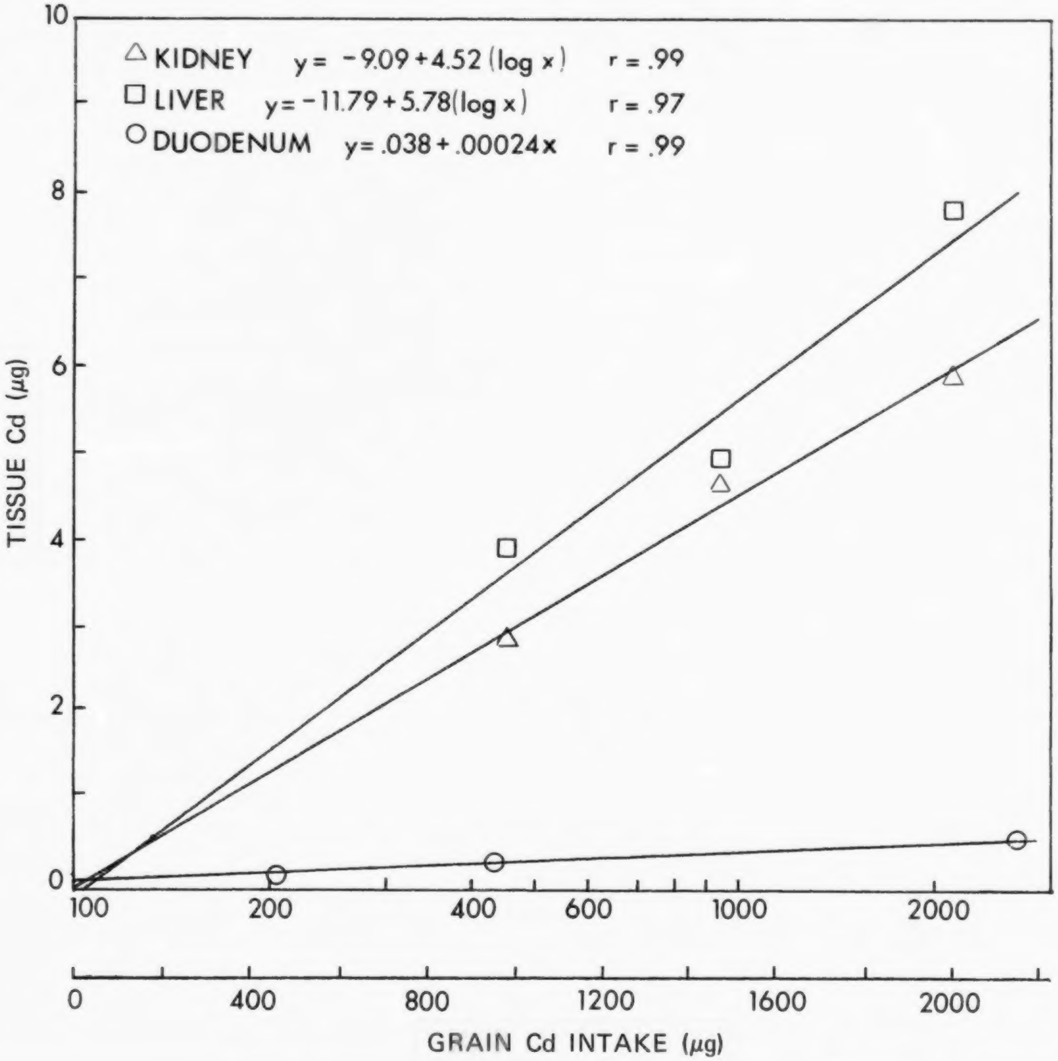

Figure 111. Relationship between total amounts of Cd accumulated in pheasants fed grain from sludge-treated plots and total amounts of Cd ingested as a constituent of grain. Total amounts of Cd in bird tissues and ingested grain are amounts in excess of levels observed in control tissues.

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birds fed grain from maximum sludge treated plots as compared to birds fed grain from control plots. Recognizing that it is rather hazardous to extrapolate beyond the experimental data, the above analysis was included mainly as an illustration of why determinations of Cd levels in animal tissues may be difficult to relate to levels of Cd cycling in the environment.

No significant difference was found in liver and kidney weights of pheasants fed grain having significantly different concentrations ofZn, Cd, Ni, Mn, K and P. In connection with weights of organs, it was shown in Figure 111 that more total Cd was retained in liver than in kidney tissue even though the latter organ contained higher concentrations (Table 78). Dry liver weights were about 6.6 times higher than dry kidney weights. Concentrations of Cd in livers were significantly correlated ($P \leq 0.01$) with levels of the element in kidneys from pheasants, as illustrated in Figure 112.

EFFECTS OF SEWAGE SLUDGE FERTILIZED CORN ON GROWING SWINE

General Description

In 1974 corn grain was harvested from the control and sludge-amended plots of the long-term continuous corn study which was initiated in 1968 and described in Section II. Corn harvested from these plots after six years of sludge treatment was ground and incorporated as 79.4% of a standard swine ration formulated for 16% protein. Due to high nitrogen applications on control plots and the high nitrogen content of the sludge, corn protein equivalents were somewhat higher (Table 81) than the means used to formulate the diet; thus, the diet formulated from control corn was 16.5% protein while the sludge corn yielded a 17.7% protein ration.

Nine weanling gilts were divided into three groups and placed in 4.7 x 1.2 m slot-floored pens equipped with automatic feeders and waterers. After a two week acclimation period, baseline parameters were collected for each animal. They were then limit-fed on the following treatment regimen: Group 1) Control-corn diet for 56 days; Group 2) sludge-corn diet for 14 days followed by control-corn diet for 42 days; Group 3) sludge-corn diet for 56 days.

Measurements of potential manifestations of toxicity (e.g. electroencephalography, electrocardiography, clinical chemistry, hematology and histopathology) were conducted by recognized specialists using standard techniques.

Total body fat was estimated by a variation of the potassium-40 method of Lohman et al. (1966). The swine were scrubbed and placed within a total body counter at various times during the course of the experiment. Potassium-40 counts were converted to grams potassium in each gilt. To calculate the percent carcass fat, the following equation was derived for swine from

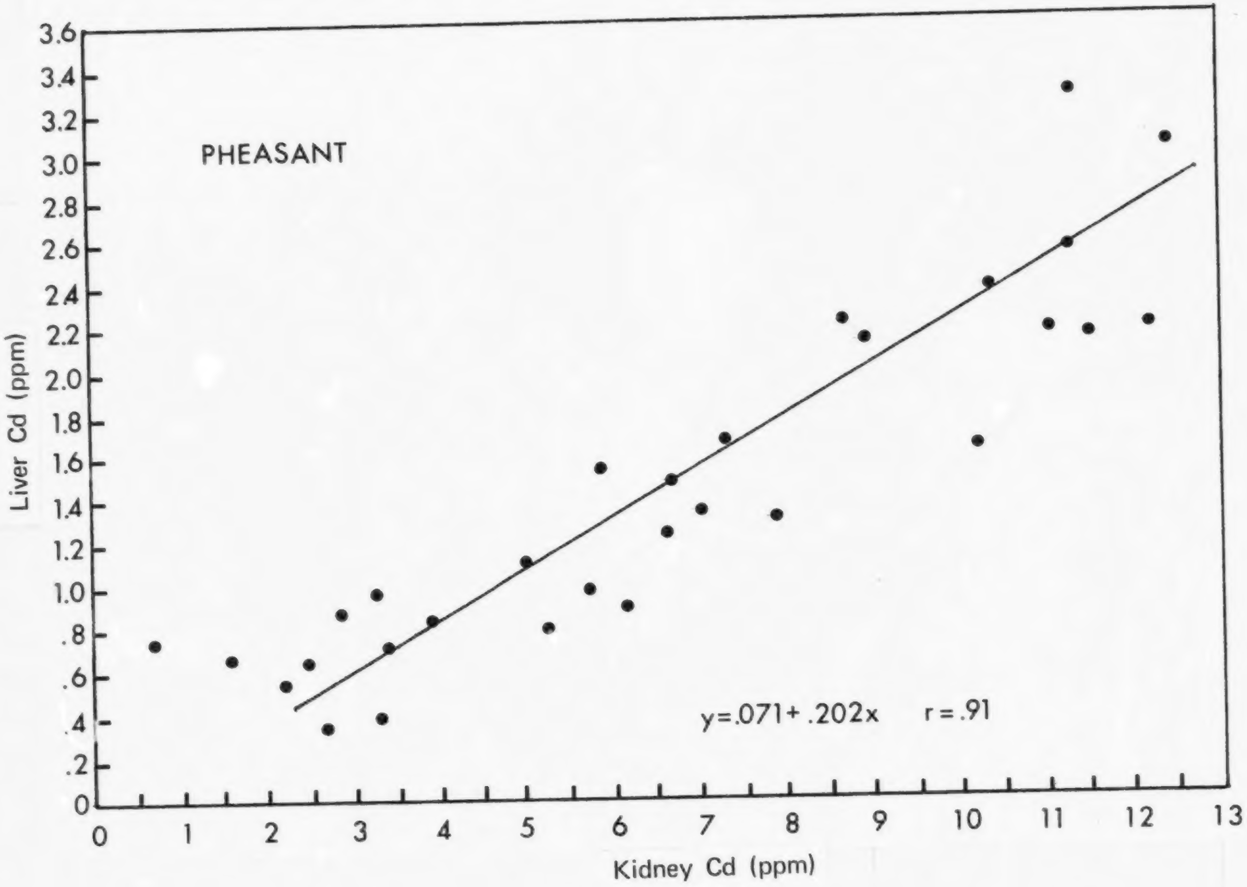

Figure 112. Correlation of Cd levels (ppm d.w.) in liver and kidney tissues from hen pheasants.

TABLE 81. AVERAGE COMPOSITION OF CORN GRAIN FED TO GILTS.

Element	Control corn	Sludge-fertilized corn	Significance*
	%		
N	1.74	1.98	n.d.
P	0.30 ± 0.02	0.33 ± 0.01	5
K	0.47 ± 0.03	0.48 ± 0.01	n.s.
Mg	0.12 ± 0.01	0.13 ± 0.005	n.s.
	ppm		
Ca	23.48 ± 2.35	26.65 ± 0.41	5
Na	7.09 ± 2.52	15.10 ± 0.76	1
Zn	26.8 ± 2.0	51.9 ± 1.0	1
Cd	0.10 ± 0.01	0.56 ± 0.02	1
Ni	0.66 ± 0.06	1.28 ± 0.06	1
Cu	1.99 ± 0.06	2.22 ± 0.10	1
Mn	7.40 ± 0.12	6.98 ± 0.09	1
Fe	14.23 ± 1.37	18.45 ± 0.53	1

*n.d. Not determined
n.s. Not significant
5 or 1 Significance at the 5 or 1 percent probability level.

experimental data:

$$\% \text{ Carcass fat} = 20.31 - 0.157\ X_1 + 0.437\ X_2 \text{ where:}$$

$$X_1 = \text{whole body potassium (g)}$$

$$X_2 = \text{body weight (Kg)}$$

Weights were recorded weekly during the experiment and samples of blood were collected by vena cava puncture for clinical chemistry and hematology. One week before termination of the study, electroencephalograms and electrocardiograms were recorded for each pig and compared to data collected prior to initiation of feeding the experimental diets.

The gilts were terminated at 56, 57 and 58 days by electrical stun and exsanguination. An apical section of liver was immediately removed, homogenized with an ultrasonic tissue grinder in 0.15 M Tris-KCl (pH 7.8) and microsomes were isolated by differential centrifugation (Wilson and Hansen, 1975). Selected organs were trimmed and weighed and tissues were either fixed in 10% buffered formalin for histological examination or placed in plastic vials and frozen for later metal analysis.

Discussion of Results

Composition of Swine Diet--

Four replicate samples of the corn used in both diets were analyzed for various metals to determine specific differences in the diets. Table 81 shows that several metals were present at significantly higher concentrations in the sludge-corn than in the control corn, while Mn was present in lower concentrations. Also, the corn from sludge-amended plots contained higher nitrogen levels.

Swine Performance--

The groups on sludge fertilized corn generally outperformed the control group, but the differences were not statistically significant (Figure 113). All three groups responded similarly to a week of particularly severe weather (days 18-25), but recovered rapidly. Each group received 456 to 459 kg of feed during the total 73-day experimental period; feed efficiencies (kg gained/100 kg feed) were: Control, 22.9; 14 day, 22.9; 56 day, 25.5. All groups maintained a total carcass fat value of 20-23% as a result of limit-feeding. Under identical conditions, but with free-choice feeding, a similar group of pigs increased from 20-22% fat to 32-34% fat in 84 days.

Concentrations of Selected Elements In Swine Tissues--

By methods similar to those used in the pheasant study concentrations of several chemical elements were determined in samples of liver, spleen, kidney, muscle, brain, and bone from swine assigned to the 3 feeding regimens. Concentrations of Zn, Cd, Cu, Fe and Mn in various swine tissues are presented in Table 82. From these data it may be observed that only concentrations of Cd were increased and only in liver and kidney tissues ($P \leq 0.05$) as a result of feeding corn grain having elevated levels of Cd. The mean

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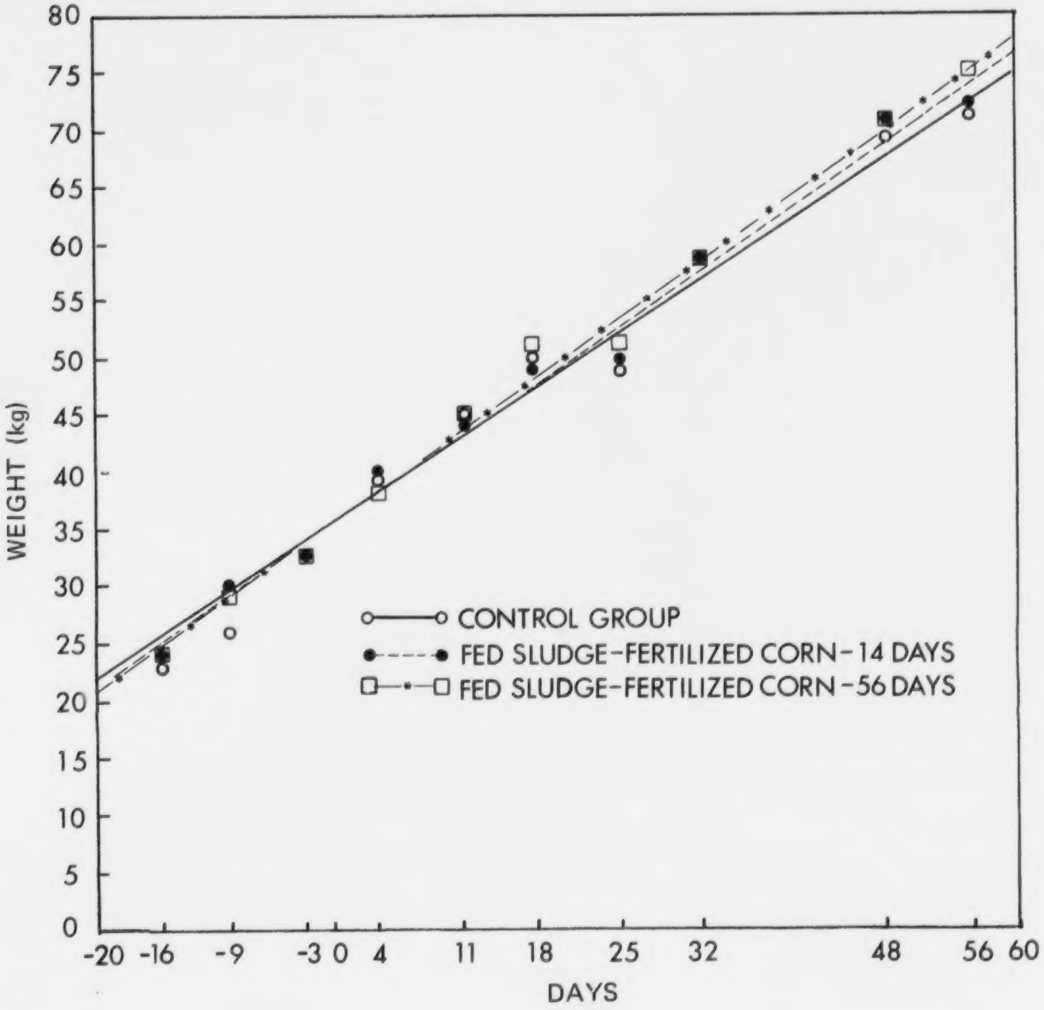

Figure 113. Mean weight gains of weanling gilts fed grain from control and sludge-fertilized plots.

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TABLE 82. MEAN CONTENTS OF FAT AND SELECTED ELEMENTS IN SEVERAL TISSUES AND BLOOD OF SWINE FED CORN GRAIN FROM CONTROL AND SLUDGE-AMENDED PLOTS.[a]

Swine group[b]	Chemical elements												Fat
	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Pb	
	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%
						Blood							
1	0.31	1.03	1.07	--	--	1364	0.15	18.6	7.7	--	0.09	--	---
2	0.30	1.01	1.09	--	--	1590	0.21	19.2	7.4	--	0.08	--	---
3	0.29	0.97	1.03	--	--	1408	0.23	21.9	7.9	--	0.08	--	---
						Brain							
1	1.18	1.23	0.44	--	--	43.0	1.00	37.2	10.3	--	0.14	--	---
2	1.53	1.55	0.53	--	--	45.0	1.19	47.1	9.1	--	0.15	--	---
3	1.33	1.31	0.57	--	--	46.2	1.20	47.6	11.2	--	0.19	--	---
						Spleen							
1	1.39	1.85	0.32	--	--	614	1.36	117	4.6	--	0.15	--	12.0
2	1.26	1.61	0.28	--	--	507	1.13	111	4.0	--	0.14	--	12.7
3	1.46	1.83	0.32	--	--	562	1.33	114	4.8	--	0.22	--	13.5
						Liver							
1	1.33	1.06	0.30	--	--	616	12.5	198	13.9	--	0.19	--	10.2
2	1.24	1.08	0.29	--	--	596	13.1	217	13.6	--	0.27	--	11.2
3	1.25	1.09	0.30	--	--	409	13.0	185	12.3	--	0.32	--	9.9
LSD						163*					0.08*		
						Kidney							
1	1.31	1.26	0.79	--	--	168	7.7	127	22.6	--	0.66	--	12.1
2	1.21	1.16	0.78	--	--	144	6.8	136	26.7	--	0.78	--	10.2
3	1.26	1.25	0.88	--	--	138	6.4	126	26.7	--	1.41	--	11.9
LSD							0.8*				0.42*		

(continued)

TABLE 82. (continued)

Swine group[b/]	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Pb	Fat
						Chemical elements							
	-------------%------------				---------------------------mg/kg---------------------------								-%--
						Muscle (left ham)							
1	0.75	1.23	0.13	--	--	40.0	0.49	60	2.9	--	0.09	--	8.8
2	0.78	1.31	0.13	--	--	33.8	0.72	53	2.8	--	0.07	--	8.6
3	0.76	1.28	0.15	--	--	34.7	0.47	60	3.1	--	0.08	--	8.3
						Bone (foreleg metacarpal)							
1	13.73	0.08	0.51	20.7	51.1	33.6	1.93	170	0.70	0.26	0.05	5.2	---
2	14.41	0.06	0.49	22.1	57.3	29.6	1.93	186	1.2	0.25	0.06	4.4	---
3	13.59	0.08	0.53	20.6	54.4	26.5	1.77	159	0.6	0.20	0.06	3.0	---
LSD				1.2*									

a/ Concentrations of chemical elements are expressed as fat free, dry weights.

b/ Group 1 = control grain; Group 2 = 14 days on grain from sludge-fertilized plots; Group 3 = 56 days on grain from sludge-fertilized plots.

*,** Significantly different at $P \leq 0.05$.

concentrations of Cd in the mixture of grain from ½-maximum and maximum-sludge-treated plots, harvested in 1974, for use in the feeding study was 0.56 mg/kg, whereas grain from control plots had Cd contents of only 0.10 mg/kg. It may also be observed that concentrations of Fe in liver and Mn in kidney tissues of swine fed grain from sludge-fertilized plots were lower than levels in liver from swine fed grain from control plots. The decrease in concentrations of Fe in liver could not have been predicted on the basis of contents in grain, because 1974 grain from sludge-fertilized plots contained about 4 mg/kg more Fe than grain from control plots. However, levels of Mn in grain from sludge-amended plots were about 0.4 mg/kg less than concentrations in grain from control plots.

As was the case in the pheasant feeding study, levels of Cd in liver and kidney tissues from swine were significantly correlated ($P \leq 0.01$) (Figure 114).

Clinical Effects--

No central nervous system response was related to treatment. One gilt from each group showed normal electroencephalograms (EEG). One control and one 56-day gilt exhibited definite EEG spikes indicative of small areas of neuronal irritation or necrosis. The other animals showed abnormalities which were of insufficient magnitude to distinguish from interpretive variations.

Electrocardiograms at the initiation and termination of the study also failed to reveal treatment related differences. Pulse rates were greater in two animals at both readings, presumably due to individual variations. The duration of the PR interval, the QT segment and the QRS wave was the same for all groups.

Levels of serum electrolytes were generally within the reported normal range for swine (Table 83), although there were some minor fluctuations; terminal sodium and potassium levels for the group receiving treated feed for 14 days were significantly different from controls and below the lower limit of the normal range. Blood glucose and blood urea nitrogen (BUN) values, although also within the normal range for swine, were significantly higher in the 56-day treatment group (Table 84). The high creatinine phosphokinase (CPK) values for the 56-day group were highly variable and similar, gilt-for-gilt, to values obtained before feeding sludge-corn. It probably represented an individual variation or pre-existing condition.

Hepatic microsomal mixed-function oxidase activity, as measured by the *in vitro* O-dealkylation of *p*-nitrophenetole, is shown in Table 85. Swine fed sludge fertilized corn for only 14 days did not differ from the controls, but those fed for 56 days had higher microsomal protein concentrations but lower and more variable hepatic microsomal O-dealkylation activity. The kinetic evaluation of microsomal preparations is tentative, but it appeared that swine liver microsomes contained or were contaminated with a non-P_{450} enzyme system that competed for *P*-nitrophenetole. The terminal oxidase in the MFO electron transport chain, cytochrome P-450, is a heme protein and, thus, susceptible to fluctuations in Fe metabolism.

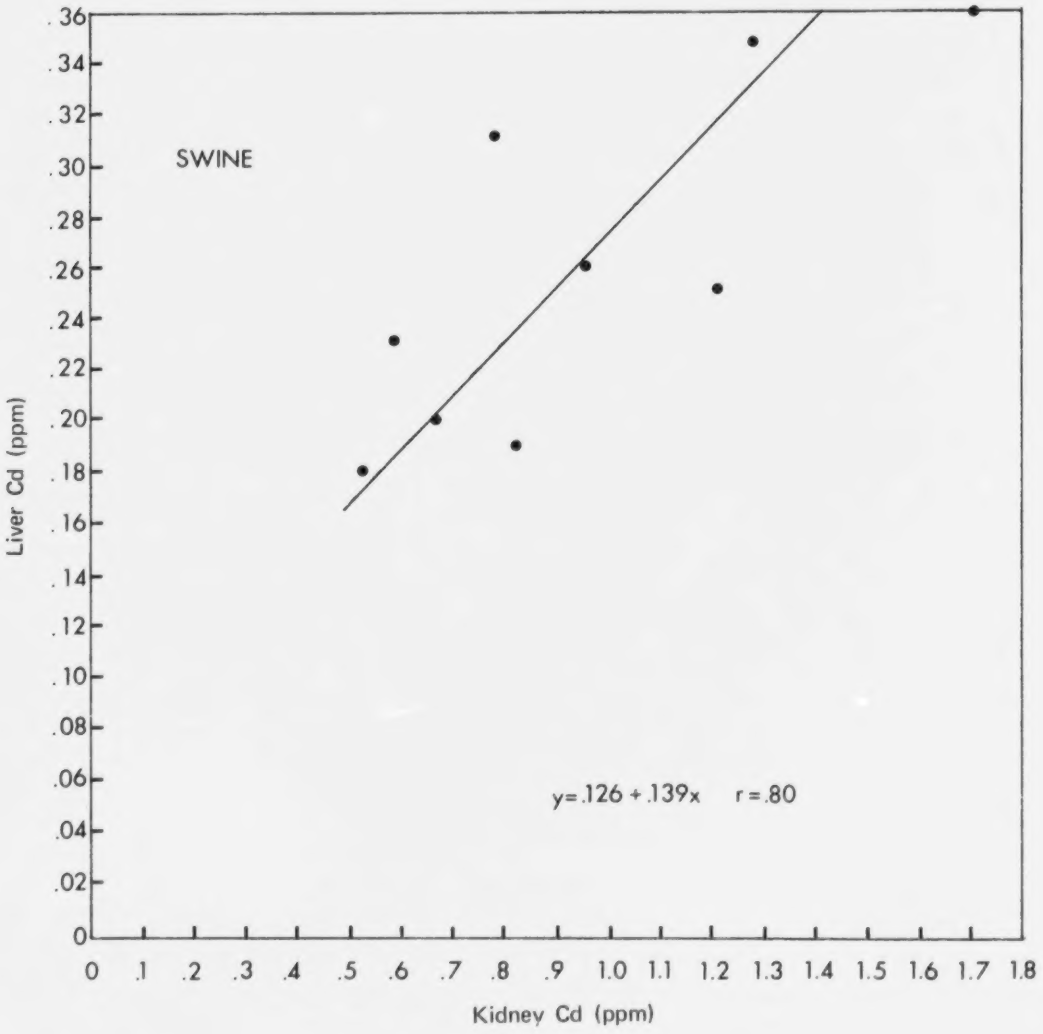

Figure 114. Correlation of Cd levels (ppm d.w.) in liver and kidney tissues from female swine.

TABLE 83. SERUM ELECTROLYTES IN SWINE FED CONTROL AND SLUDGE-FERTILIZED CORN.[a]

Group	Time (days)	Sodium (meq)	Potassium (meq)	Phosphate (mg%)	Calcium (mg%)	Total protein (g%)
Control	56	147 ± 2.1	4.30 ± 0.23	7.5 ± 0.3	9.9 ± 0.3	5.94 ± 0.23
14 day	14	135 ± 2.0	4.38 ± 0.33	8.9 ± 4.4	11.0 ± 0.1	6.37 ± 0.06
	56[b]	129 ± 0.8	3.88 ± 0.05	8.1 ± 0.3	10.4 ± 0.1	5.91 ± 0.06
56 day	56	143 ± 4.3	4.44 ± 0.19	9.1 ± 0.8	10.8 ± 0.4	6.30 ± 0.32

[a] Mean ± S.D.

[b] n=4 due to hemolysis of both replicates from one animal.

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TABLE 84. BLOOD CHEMISTRY PARAMETERS IN SWINE FED CONTROL AND SLUDGE-FERTILIZED CORN.[a]

		CRT[b]	AP[b]	CPK[b]	SGPT[b]	LDH[b]	BUN[b]	Glu[b]
Control	$\bar{x}$	0.33	36.33	83.0	54.2	194	10.7	103.8
	SD	± 0.08	± 7.87	± 7.5	± 2.6	± 5	± 1.3	± 5.5
14-Day[c]	$\bar{x}$	0.53	28.25	96.0	59.3	201	11.5	105.3
	SD	± 0.05	± 2.60	± 4.1	± 3.9	± 18	± 0.0	± 14.6
56-Day	$\bar{x}$	0.60	37.75	168.5	61.3	210	19.2	128.8
	SD	± 0.09	± 4.88	± 87.4	± 7.6	± 22	± 1.3	± 4.9

a/ Terminal samples.

b/ CRT, Creatinine, mg/100; AP, Alkaline phosphatase, hycel international units; CPK, Creatinine phosphokinase, hycel international units; SGPT, Serum glutamic-pyruvate transiminase, hycel international units; LDH, Lactate dehydrogenase, hycel international units; BUN, Blood urea nitrogen, mg/100; Glu, Glucose, mg/100.

c/ Both replicate samples from one animal hemolyzed so that this represents the mean of two replicates from two animals.

TABLE 85. HEPATIC MICROSOMAL O-DEALKYLATION OF *p*-NITROPHENETOLE IN SWINE FED SEWAGE SLUDGE FERTILIZED CORN FOR 0, 14 OR 56 DAYS.[a]

Group	Microsomal protein (mg/100 mg fw)	Specific activity[b]	
		0.05 mM[c]	0.25 mM[c]
Control	0.65 ± 0.14[d]	7.10 ± 0.95	9.47 ± 1.16[e]
14-Day	0.58 ± 0.11[d]	7.95 ± 0.39[e]	9.21 ± 0.41[e]
56-Day	1.02 ± 0.09	4.94 ± 2.45	5.47 ± 2.37

[a] Mean ± S.D. for n=3.

[b] n moles *p*-nitrophenol produced/min/mg protein.

[c] Substrate (*p*-nitrophenetole)concentration.

[d] Significantly different from 56-day group by Tukey's multiple means test at P<0.003.

[e] Significantly different from 56-day group by Tukey's multiple means test at P<0.03.

Hematological parameters are summarized in Table 86. Red blood cell counts, hemoglobin and hematocrits were lower at the earlier sampling time (Day 0) in all groups. The mean corpuscular volume (MCV) and mean corpuscular hemoglobin (MCH) of the control gilts at 56 days were significantly different from both treated groups and below the lower limit of the normal range for swine (50 and 17, respectively).

Gross Pathology--

No discernable gross lesions were observed in any of the swine at termination. No consistent significant changes in relative organ weights were detected (Table 87). The relative liver and kidney weights in the 56-day group, were slightly higher than controls.

Histopathology--

Detectable lesions were few and these were seen in both the control and treatment groups. A few perivascular cuffs of plasma cells were seen in the white matter of the cerebellum and in the lepto meniges of the brains of two pigs in the control group and to a lesser degree in one of each treatment group. There was a marked focal interstitial proliferation of R. E. cells in the kidney of one pig in the 56 day treatment group and similar lesions but to a lesser degree in one of each of the other groups. The only other noteworthy lesions were those caused by moderate to heavy parasitism and these were seen in all groups.

EFFECTS ON PERFORMANCE AND REPRODUCTION OF RATS FED DIETS FORMULATED FROM SEWAGE SLUDGE-FERTILIZED CORN AND SOYBEANS

General Description

In 1974 corn grain and soybeans were harvested from control and sludge-amended plots of the long-term field studies discussed in Section II and used to formulate diets for rats. Sixty weanling Sprague-Dawly rats (27 male and 33 female) were acclimated for one week and then subdivided according to 14% protein diets formulated from control or grain from sludge-fertilized corn and soybeans (78.7% corn grain + 15.1% soybean meal). Due to the necessity of conserving custom diets, the two groups (custom control and sludge-fertilized) were reduced to 5 males and 6 females after 4 weeks. The remaining rats were fed commercial rat food (Wayne's Lab Blox) through the remainder of the study. Two males were eliminated at this time. At 6 weeks, 3 males and 3 females from each treatment group were to be sacrificed for gross pathology and metal residue determinations, but one female on the sludge-fertilized grain diet was inadvertently sacrificed, instead of a male. These rats had been on the commercial diet 2 weeks prior to sacrifice.

Breeding was begun when the rats were 90 days old and first litters were born 11 to 13 weeks after the feeding study was initiated. At 2 days old, litters were randomly reduced to a maximum of 8 pups per dam. Culled pups from large litters were subjected to whole body chemical analyses. The

TABLE 86. HEMATOLOGICAL PARAMETERS IN SWINE FED SEWAGE SLUDGE-FERTILIZED CORN.[a]

Group	Day	RBC[b]	WBC[b]	Hb[b]	Ht[b]	MCV[b]	MCH[b]	MCHC[b]
Control	0	6.34 ± 0.29	18.5 ± 3.1	12.7 ± 1.1	37.7 ± 2.1	59.4 ± 2.9	20.0 ± 1.4	33.6 ± 1.0
	38[c]	7.51 ± 0.32	16.2 ± 1.1	13.4 ± 0.9	42.0 ± 1.4	56.0 ± 0.5	17.8 ± 0.4	31.8 ± 1.1
	56	9.21 ± 0.74	15.4 ± 0.4	14.0 ± 0.9	42.5 ± 2.7	46.3 ± 3.7	15.2 ± 1.2	32.8 ± 0.6
14 Day	0[c]	6.60 ± 0.05	15.2 ± 0.1	12.2 ± 0.2	37.0 ± 0.0	56.0 ± 0.4	18.4 ± 0.1	32.8 ± 0.6
	14	8.08 ± 0.95	21.0 ± 1.3	12.5 ± 0.8	40.7 ± 3.2	50.5 ± 2.8	15.5 ± 1.3	30.7 ± 1.0
	38[c]	7.29 ± 0.06	18.0 ± 0.4	12.7 ± 0.6	41.8 ± 0.4	57.3 ± 1.0	17.4 ± 1.1	30.3 ± 1.3
	56[c]	7.69 ± 0.54	18.1 ± 0.9	12.8 ± 0.2	40.9 ± 1.0	53.3 ± 2.5	16.7 ± 1.0	31.4 ± 0.4
56 Day	0[c]	6.56 ± 0.02	14.8 ± 2.0	11.9 ± 1.0	34.5 ± 2.1	52.7 ± 3.0	18.2 ± 1.5	34.5 ± 0.8
	38	7.26 ± 0.20	16.2 ± 3.4	12.6 ± 0.1	41.3 ± 1.2	57.0 ± 1.7	17.4 ± 0.4	30.5 ± 0.9
	56	7.63 ± 0.44	16.4 ± 2.4	13.1 ± 0.7	41.2 ± 1.4	54.1 ± 2.2	17.2 ± 0.5	31.8 ± 1.4

[a] Mean ± S.D.; n=3.

[b] RBC, Red Blood Cells X 10^6; WBC, White Blood Cells X 10^3; Hb, Hemoglobin (g%); Ht, Hematocrit (%); MCV, Mean Corpuscular Volume (μ^3); MCH, Mean Corpuscular Hemoglobin (10-12g); MCHC, Mean Corpuscular Hemoglobin Concentration (%).

[c] n=2 due to sample clotting and/or hemolysis.

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TABLE 87. RELATIVE ORGAN WEIGHTS IN SWINE FED SLUDGE-FERTILIZED CORN.[a/]

Organ	Organ weight(g)/body weight (kg)		
	Control	14-Day	56-Day
Liver	18.50 ± 2.76	16.87 ± 0.74	20.31 ± 1.71
Kidney	4.56 ± 0.64	4.32 ± 0.80	4.98 ± 0.93
Spleen	1.32 ± 0.07	1.39 ± 0.12	1.25 ± 0.09
Heart	3.86 ± 0.28	4.01 ± 0.06	3.86 ± 0.35
Pancreas	1.52 ± 0.15	1.16 ± 0.28	1.36 ± 0.17
Brain	1.21 ± 0.15	1.33 ± 0.06	1.14 ± 0.07
Adrenal	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.00
Thyroid	0.09 ± 0.03	0.12 ± 0.01	0.09 ± 0.02

[a/] Mean ± S.D.; n=3.

remaining pups were weaned at 21 days, reared for 7 days on commercial rat food and then sacrificed. Females were rebred 2 to 4 weeks after weaning their first litter and males were terminated after it was confirmed that the females were pregnant (17 ± 2 weeks). Females were terminated after weaning their second litter (20 ± 23 weeks).

Discussion of Results

Concentrations of Selected Elements in Corn Grain and Soybeans--

Concentrations of several elements in corn grain and soybeans harvested from control and sludge-amended plots are shown in Table 88. Only Mg concentrations in both corn grain and soybeans and K concentrations in corn grain were unaffected by sludge applications. Concentrations of most elements were increased by sludge applications, but Mn concentrations in corn grain and Na, Ca, and Cu concentrations in soybeans were decreased as a result of sludge applications.

Concentrations of Selected Elements in Rat Tissues--

Concentrations of several elements in brain, spleen, heart, liver, kidney, muscle, testes, ovaries, lung, hair, and femur bone from male and female rats fed diets formulated with corn and soybeans from control and sludge-amended plots are shown in Tables 89 and 90. Rats terminated at the end of 6 weeks contained about the same concentrations of the several elements in all tissues regardless of diet (Table 89). However, female rats contained significantly higher concentrations of Fe in their spleen and liver than male rats. At the end of 20 weeks concentrations of only a few elements in rat tissues were affected by different levels in diets (Table 90). Concentrations of Cd were increased in the liver of female rats by increased dietary levels, but not in livers of male rats. Concentrations of Cd were higher in the kidneys of both male and female rats fed diets formulated with sludge-fertilized corn and soybeans. Female rats on diets of sludge-fertilized materials had higher Mn levels in kidneys than those on diets of control grains. Significantly higher concentrations of Na ($P \leq 0.05$) were found in the hair of male rats fed corn grain and soybeans produced on sludge-amended plots. In rats terminated after 20 weeks testicular Zn concentrations were lower than at 6 weeks of those fed diets of sludge-fertilized corn grain and soybean meal. Whole bodies of 3 pups from each of the litters from both treatment groups were dried, fat-extracted, and analyzed for concentrations of several elements. The only observed differences were lower Mn and Mg concentrations in pups from dams which were fed diets formulated with sludge-fertilized corn and soybeans (Table 91).

Performance of Rats--

Considered as large groups, weight gains were the same for males and females in both treatment groups (Table 92). Subdividing into custom and custom plus commercial diet, 15 week weights were still not different between treatment groups (Table 93).

TABLE 88. CONCENTRATIONS OF SELECTED ELEMENTS IN CORN GRAIN AND SOYBEANS USED TO FORMULATE DIETS FOR RATS.[a]

Treatment[b]	Chemical element										
	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd
	mg/kg										
					Corn grain						
Control	3037	4678	7.1	23.5	1238	14.23	7.40	26.8	1.99	0.66	0.10
S.F.	3293	4787	15.1	26.6	1258	18.45	6.98	51.9	2.22	1.28	0.56
Significance	0.05	n.s.	0.01	0.05	n.s.	0.01	0.01	0.01	0.01	0.01	0.01
					Soybeans						
Control	4948	19273	74.0	72.3	2062	62.1	20.7	29.4	11.3	7.90	0.17
S.F.	5703	20507	47.4	36.1	2195	57.1	38.9	50.5	10.9	10.56	0.91
Significance	0.01	0.05	0.01	0.01	n.s.	0.01	0.01	0.01	0.01	0.01	0.01

a/ Dry weight

b/ S.F. = Grain or soybeans from sludge-fertilized plots.
Significance - At $P \le 0.05$ or $P \le 0.01$

n.s. No significance

TABLE 89. CONCENTRATIONS OF SELECTED ELEMENTS IN VARIOUS TISSUES OF MALE AND FEMALE RATS FED A CONTROL DIET AND DIETS FORMULATED FROM SLUDGE-FERTILIZED CORN AND SOYBEANS FOR 6 WEEKS.a/

Sex	Treatment	Chemical element					
		P	Fe	Mn	Zn	Cu	Cd
		--%-	------------------------mg/kg				------------------------
					Brain		
M	Control	1.71	131	1.52	67	9.6	0.10
M	S.F.	1.92	85	1.68	72	8.8	0.21
F	Control	1.82	79	1.72	70	8.8	0.32
F	S.F.	1.47	75	1.39	61	8.2	0.10
					Spleen		
M	Control	0.84	495	0.72	64	13.4	0.21
M	S.F.	0.93	578	1.24	70	12.8	0.16
F	Control	1.03	813	0.89	84	11.8	0.35
F	S.F.	0.92	934	1.40	81	10.4	0.20
					Heart		
M	Control	0.97	359	1.45	88	16.4	0.11
M	S.F.	0.65	151	0.82	56	11.1	0.13
F	Control	0.88	223	1.21	75	16.6	0.14
F	S.F.	0.84	209	1.44	75	16.0	0.18
					Liver		
M	Control	1.08	254	6.2	69	10.3	0.07
M	S.F.	0.99	182	6.1	71	9.9	0.19
F	Control	0.92	368	5.7	63	8.9	--
F	S.F.	0.85	429	5.2	60	8.5	0.10

(continued)

TABLE 89. (continued)

Sex	Treatment	P	Fe	Mn	Zn	Cu	Cd
		Chemical element					
		--%-	--------------------------mg/kg------------------------				
				Kidney			
M	Control	0.96	168	2.2	80	22.4	0.41
M	S.F.	0.74	117	1.5	66	18.0	0.29
F	Control	0.82	191	1.7	78	23.6	0.53
F	S.F.	0.72	171	2.1	93	16.5	0.48
				Muscle			
M	Control	1.05	38	0.5	44	4.3	0.10
M	S.F.	0.81	51	0.6	49	5.4	0.14
F	Control	1.01	75	0.9	54	4.4	0.10
F	S.F.	0.81	53	0.6	40	4.7	0.09
				Testes			
M	Control	1.04	61	1.2	126	6.4	0.13
M	S.F.	1.51	92	2.1	212	15.0	0.08
				Ovaries			
F	Control	--	--	--	158	--	1.17
F	S.F.	--	--	--	169	--	0.86

a/ Dry weight basis.
S.F. = Diets formulated from sludge-fertilized corn and soybeans.

TABLE 90. CONCENTRATIONS OF SELECTED ELEMENTS IN VARIOUS TISSUES OF MALE AND FEMALE RATS FED A CONTROL DIET AND DIETS FORMULATED FROM SLUDGE-FERTILIZED CORN AND SOYBEANS FOR 20 WEEKS.a/

Sex	Treatment	Chemical element											
		P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Pb
		---------%---------			----------mg/kg----------								
							Brain						
M	Control	0.46	-	-	-	-	161	3.0	93	13.2	-	0.32	-
M	S.F.	0.48	-	-	-	-	180	3.6	85	14.0	-	0.40	-
							Spleen						
M	Control	0.93	-	-	-	-	4610	2.0	60	6.7	-	0.06	-
M	S.F.	0.88	-	-	-	-	4102	1.4	54	3.7	-	0.13	-
F	Control	-	-	-	-	-	5248	2.1	78	6.3	-	0.13	-
F	S.F.	-	-	-	-	-	6126	1.6	74	4.7	-	0.10	-
							Heart						
M	Control	0.28	-	0.35	-	-	354	1.6	54	16.9	-	0.05	-
M	S.F.	0.34	-	0.35	-	-	339	2.0	56	17.9	-	0.06	-
							Liver						
M	Control	0.84	1.38	0.23	84	606	468	6.8	83	11.2	-	0.19	-
M	S.F.	0.75	1.34	0.24	83	592	454	7.2	84	11.1	-	0.15	-
F	Control	-	0.68	0.16	189	551	621	5.1	62	8.4	0.49	0.06	0.63
F	S.F.	-	0.69	0.16	138	548	655	5.7	59	8.1	0.23	0.14	0.54
	LSD											0.06*	
							Kidney						
M	Control	0.54	-	-	-	-	151	1.5	45	16.3	-	0.10	-
M	S.F.	0.63	-	-	-	-	170	1.9	56	19.9	-	0.29	-
	LSD											0.18**	
F	Control	-	-	-	-	-	417	2.7	94	57	-	0.35	-
F	S.F.	-	-	-	-	-	367	3.7	113	91	-	2.09	-
	LSD							1.0**				1.08**	

(continued)

TABLE 90. (continued)

Sex	Treatment	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Pb
		---------%---------			--------------------------			mg/kg					------------------------
							Muscle						
M	Control	0.67	-	-	-	-	45	0.52	39	4.7	-	0.08	-
M	S.F.	0.54	-	-	-	-	71	0.47	42	5.2	-	0.14	-
F	Control	-	1.24	0.16	-	-	67	0.52	45	1.9	-	0.03	2.00
F	S.F.	-	1.24	0.15	-	-	55	0.66	39	3.0	-	0.03	2.73
							Testes						
M	Control	-	-	-	-	-	150	2.2	164	9.1	-	0.06	-
M	S.F.	-	-	-	-	-	137	1.5	116	7.6	-	0.09	-
							Lung						
M	Control	0.85	-	-	-	-	-	0.33	70	8.3	-	0.16	-
M	S.F.	1.05	-	-	-	-	-	0.61	77	10.2	-	0.18	-
F	Control	0.68	0.66	0.53	-	-	516	3.3	63	5.8	-	0.07	1.10
F	S.F.	0.77	0.83	0.50	-	-	437	1.7	65	7.3	-	0.04	2.17
							Hair						
M	Control	0.03	0.38	0.05	-	-	13	1.2	148	15.3	1.11	0.22	0.81
M	S.F.	0.02	0.55	0.06	-	-	18	1.1	153	11.4	0.53	0.36	1.28
	LSD			0.01*									
							Femur bone						
		----------------		%		----------------	-------------------		mg/kg				-------------------
M	Control	13.2	0.09	0.44	29.1	0.40	83	3.5	282	4.7	1.49	0.29	7.66
M	S.F.	13.3	0.09	0.46	28.8	0.33	76	4.2	256	5.1	1.08	0.15	6.40
F	Control	16.4	0.02	0.34	33.0	3.87	147	6.9	408	13.4	1.27	0.46	6.59
F	S.F.	16.7	0.02	0.35	32.5	2.50	134	6.7	387	8.5	3.22	0.71	3.81

a/ Dry weight basis.
S.F. = Diets formulated from sludge-fertilized corn and soybeans.
*,** = Significantly different at P≤0.05 and P≤0.01, respectively.

TABLE 91. CONCENTRATIONS OF SELECTED ELEMENTS AND FAT IN THE FIRST GENERATION OF PUPS FROM RATS FED A CONTROL DIET AND DIETS FORMULATED FROM SLUDGE-FERTILIZED CORN AND SOYBEANS.a/

Treatment	Element											
	Fat	P	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd
	%						mg/kg					
Control	41.1	2.89	1.73	0.98	2.28	0.18	167	1.82	117	11.3	0.99	0.026
S.F.	44.0	2.71	1.64	0.92	2.71	0.16	176	1.58	116	11.2	0.81	0.020
LSD						0.019**		0.24*				

a/ Dry weight basis.
S.F. = Diets formulated from sludge-fertilized corn and soybeans.
*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 92. COLLECTIVE MEAN WEIGHTS OF ADULT RATS DURING STUDY.

	Males						Females					
	Control			Sludge			Control			Sludge		
Week	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.	n	$\bar{x}$	S.D.
1	14	74.6	5.8	13	77.9	9.0	11	67.7	6.5	12	68.1	8.0
2	14	119.5	8.9	13	117.4	15.5	11	103.0	14.2	12	100.2	10.7
3	14	165.5	12.1	13	158.7	20.1	11	131.0	8.8	12	130.7	12.2
5	14	250.6	12.0	13	236.3	37.0	11	168.1	13.6	12	170.0	14.8
7	11	303.6	14.0	9	309.7	21.8	8	193.3	14.5	10	194.3	15.4
10	11	348.3	16.5	9	346.1	18.3	8	281.5	33.8	10	298.6	36.5
15	10	389.0	20.0	9	392.0	28.9	8	245.4	21.9	10	250.4	13.7
17	8	404.3	23.9	6	405.7	31.1	8	281.3	33.0	10	295.1	24.1
20	5	413.8	29.4	3	439.0	37.2	8	296.4	39.9	10	299.3	23.4

TABLE 93. WEIGHTS OF EXPERIMENTAL GROUPS OF ADULT RATS DURING FEEDING STUDY.

Time (weeks)	Control				Sludge-fertilized			
	Custom		Commercial[a]		Custom		Commercial[a]	
	n	Weight (g)	n	Weight (g)	n	Weight (g)	n	Weight (g)
	Male							
1	5	73 ± 7	5	75 ± 7	5	80 ± 7	4	81 ± 5
5	5	239 ± 11	5	251 ± 15	5	240 ± 18	4	261 ± 20
10	5	346 ± 13	5	349 ± 22	4	332 ± 8	4	361 ± 12
15	5	388 ± 17	5	390 ± 25	4	373 ± 17	4	411 ± 27
	Female							
1	6	67 ± 7	2	76 ± 1	6	68 ± 8	4	71 ± 10
5	6	169 ± 17	2	168 ± 5	6	162 ± 12	4	183 ± 15
10	6	285 ± 34	2	272 ± 42	6	282 ± 36	4	322 ± 24
15	6	239 ± 21	2	264 ± 12	6	247 ± 14	4	256 ± 12
.0	6	289 ± 44	2	318 ± 20	6	300 ± 15	4	298 ± 35

[a] Switched to commercial ration (Wayne's Lab Blox) after 4 weeks on respective custom diet.

Reproduction Parameters--

All treatment groups performed similarly for first litters and subsequent pup performance was comparable (Table 94). It appeared that pups whose dams received the commercial diet had a slight advantage over the custom diet groups. However, this advantage was not observed in the second litters Table 95).

Pathological Examination of Rats--

There were no treatment differences in serum chemistries in male (Table 96) and female (Table 97) rats fed diets for 15 to 20 and 20 to 23 weeks, respectively. The diets formulated with grain from sludge-fertilized plots also failed to exert a detrimental effect on the blood cells of male and female rats (Tables 98 and 99).

After 4 weeks on the custom diets, it appeared that male animals receiving grains from sludge-fertilized plots might have larger testicles, but the small sample (n=2) must be considered (Table 100). This tendency was not seen later in males which had received the diets for 15 to 20 weeks (Table 101). Again, an apparent difference in female liver weights can be discounted due to lack of a reasonable pattern and a small sample for the control-commercial group (Table 102). Finally, there were no differences in the relative organ weights of first or second litter pups (Table 103, 104, and 105).

EFFECTS OF OVERWINTERING PREGNANT SWINE ON SOILS HEAVILY AMENDED WITH MUNICIPAL SEWAGE SLUDGE

General Description

As seen in the results of previous studies, feeding corn grain from sludge-amended plots to pheasants and swine and both corn grain and meal from soybeans produced with sludge fertilization to rats failed to elicit any signs of toxicity. Thus it seemed desirable to conduct a "worst case" study, short of direct feeding of sludge. Weanling pigs were selected for the study because of predicted exposure through rooting and soil ingestion as well as eating the plant parts returned to the plots. Furthermore, swine are adequately hardy to withstand the winters in northern Illinois and their development and reproduction cycle was ideally suited for development on sludge-amended soil followed by breeding, gestation and nursing schedules which would bring them into heat at the beginning of the following season. Thus, the second gestation period occurred during maximum exposure to the sludge-amended soils.

Sixteen weanling purebred Berkshire gilts (Thurow Farms; Yorkville, IL) were assigned to the long-term continuous corn plots described in Section II. Assignments were made in a random fashion, except that no siblings were permitted within the same dosage group. The plots were divided between the two buffer rows that separated sludge-treatments, and individual shelters, feeders and waterers were provided. The gilts were introduced to the plots on November 4, 1975 and removed March 20, 1976. They were bred by one of

(continued on Page 538)

TABLE 94. REPRODUCTION PARAMETERS IN FIRST LITTERS (LIKE CROSSES) OF RATS FROM THE FEEDING STUDY.

Parameter	Control		Sludge-fertilized	
	Custom	Commercial[a]	Custom	Commercial[a]
Number of litters	6	2	6	6
Live pups	11.5 ± 2.3	14.0 ± 0.0	10.7 ± 5.2	10.0 ± 2.0
Dead pups	0.3 ± 0.8	0.5 ± 0.7	0.8 ± 1.3	0
Males	6.8 ± 2.3	5.5 ± 0.7	5.2 ± 2.6	4.5 ± 1.3
Females	4.7 ± 1.0	8.5 ± 0.7	5.5 ± 3.0	5.5 ± 1.3
Ratio (M/F)	1.55 ± 0.71	0.66 ± 0.13	0.89 ± 0.37	0.85 ± 0.26
Pup weight (g)				
1 day	6.6 ± 0.7	7.1 ± 0.5	6.9 ± 0.8	7.2 ± 0.7
(n)	(69)	(28)	(64)	(40)
3 week	41 ± 3	52 ± 3	44 ± 5	57 ± 4
(n)	(48)	(16)	(42)	(31)
4 week	78 ± 10	87 ± 5	78 ± 12	85 ± 8
(n)	(48)	(16)	(34)	(31)

[a] Switched to commercial ration after 4 weeks on respective custom diet.

TABLE 95. REPRODUCTION PARAMETERS IN SECOND LITTERS (CONTROL X SLUDGE AND SLUDGE X CONTROL CROSSES) OF RATS FROM THE FEEDING STUDY.

Parameter	Control		Sludge-fertilized	
	Custom	Commercial[a]	Custom	Commercial[a]
Number of litters	6	2	6	3
Live pups	12.2 ± 3.3	13.5 ± 0.7	13.5 ± 2.2	12.7 ± 4.2
Dead pups	0	0	0.2 ± 0.4	0
Males	6.2 ± 3.3	5.5 ± 2.1	7.0 ± 2.6	6.7 ± 2.5
Females	6.0 ± 2.8	8.0 ± 2.8	6.5 ± 1.5	6.0 ± 1.7
Ratio (M/F)	1.24 ± 0.84	0.78 ± 0.54	1.16 ± 0.55	1.10 ± 0.18
Pup weight (g)				
1 day	7.4 ± 1.2	6.7 ± 0.4	7.1 ± 0.5	7.6 ± 0.7
(n)	(72)	(27)	(81)	(38)
3 weeks	52 ± 7	58 ± 5	54 ± 5	60 ± 4
(n)	(46)	(16)	(48)	(24)
4 weeks	80 ± 13	77 ± 9	81 ± 10	86 ± 8
(n)	(44)	(16)	(47)	(24)

[a] Switched to commercial ration after 4 weeks on respective custom diet.

TABLE 96. CLINICAL CHEMISTRY OF MALE RATS FED ON CONTROL AND SEWAGE SLUDGE FERTILIZED CORN AND SOYBEANS FOR 15 TO 20 WEEKS.

Parameter	Control				Sludge-fertilized			
	Custom a/		Commercial a/		Custom b/		Commercial b/	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
CRT	0.32	0.18	0.56	0.17	0.55	0.10	0.60	0.24
TP	6.4	0.3	6.0	0.2	6.3	0.3	5.9	0.3
P	6.0	0.7	7.2	0.7	7.0	1.1	7.1	1.6
AP	60	9	64	15	62	17	53	9
CPK	118	38	237	51	215	130	238	178
SGPT	67	14	95	54	82	14	113	69
LDH	213	34	323	161	264	53	292	77
Ca	10.7	0.8	11.2	1.3	11.8	0.5	11.5	0.9
BUN	16	4	23	3	20	2	23	4
Glu	200	36	187	30	232	64	214	57

a/ n=5
b/ n=4

TABLE 97. CLINICAL CHEMISTRY OF FEMALE RATS FED ON CONTROL AND SEWAGE SLUDGE FERTILIZED CORN AND SOYBEANS FOR 20 TO 23 WEEKS.

	Control				Sludge- fertilized			
	Custom [a]		Commercial [b]		Custom [a]		Commercial [c]	
Parameter	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
CRT	0.90	0.41	0.90	0.14	0.83	0.52	0.78	0.39
TP	5.9	0.3	6.2	0.1	6.0	0.2	6.4	0.5
P	6.3	1.5	6.4	-	6.9	1.0	6.4	1.6
AP	70	20	64	25	64	20	63	10
CPK	94	82	46	-	101	81	150	105
SGPT	82	43	72	8	69	19	63	5
LDH	175	71	-	-	271	76	270	85
Ca	10.9	0.6	11.2	1.1	11.5	0.9	11.2	0.4
BUN	26	7	24	7	30	4	26	5
Glu	153	28	144	12	191	26	164	12

[a] n=6
[b] n=2
[c] n=4

TABLE 98. HEMATOLOGICAL PARAMETERS OF MALE RATS FED ON CONTROL AND SLUDGE-FERTILIZED CORN AND SOYBEANS DIETS FOR 15 TO 20 WEEKS.

Parameter	Control		Sludge-fertilized	
	Custom	Commercial	Custom	Commercial
n	5	5	4	4
RBC	6.38 ± 1.19	7.63 ± 0.68	6.09 ± 1.20	6.86 ± 1.51
WBC	10.68 ± 3.86	6.90 ± 2.83	7.90 ± 3.32	9.60 ± 2.64
Hb	14.1 ± 0.8	14.1 ± 0.5	14.3 ± 0.4	14.1 ± 0.8
PCV	42.5 ± 3.1	42.1 ± 2.2	43.0 ± 2.2	42.5 ± 1.5
MCV	68.8 ± 15.2	55.6 ± 6.7	73.2 ± 17.2	64.6 ± 16.9
MCH	22.8 ± 4.7	18.6 ± 2.3	24.2 ± 5.2	21.5 ± 6.0
MCHC	33.2 ± 0.8	33.5 ± 0.8	33.2 ± 0.9	33.2 ± 1.2

TABLE 99. HEMATOLOGICAL PARAMETERS OF FEMALE RATS FED ON CONTROL AND SLUDGE-FERTILIZED CORN AND SOYBEAN DIETS FOR 20 TO 23 WEEKS.

Parameter	Control		Sludge-fertilized	
	Custom	Commercial	Custom	Commercial
n	4	2	4	4
RBC	7.42 ± 0.71	8.15 ± 0.35	8.28 ± 0.84	8.47 ± 0.72
WBC	5.22 ± 0.43	5.25 ± 1.63	5.28 ± 0.52	5.95 ± 1.23
Hb	14.2 ± 1.0	14.8 ± 0.71	15.0 ± 0.7	15.8 ± 1.2
PCV	42.2 ± 3.3	43.5 ± 2.1	44.9 ± 2.0	47.6 ± 7.0
MCV	57.2 ± 4.9	53.4 ± 0.3	54.5 ± 3.4	56.1 ± 5.3
MCH	19.1 ± 0.8	18.2 ± 0.1	18.2 ± 1.0	18.7 ± 0.8
MCHC	33.5 ± 1.7	34.0 ± 0.0	33.4 ± 0.6	33.5 ± 2.2

TABLE 100. RELATIVE ORGAN WEIGHTS OF 70-DAY RATS AFTER RECEIVING DIETS FORMULATED FROM GRAIN HARVESTED FROM CONTROL AND SLUDGE-AMENDED PLOTS FOR 30 DAYS.

Organ	Relative organ weight[a] (% body)			
	Control		Sludge-fertilized	
	Male	Female	Male	Female
n	3	3	2	4
Body	276 ± 10	173 ± 14	276 ± 16	178 ± 3
Liver	4.84 ± 0.01	4.70 ± 0.16	4.82 ± 0.08	4.40 ± 0.54
Gonads	0.98 ± 0.04	0.06 ± 0.02	1.10 ± 0.02	0.06 ± 0.02
Kidneys	0.82 ± 0.07	0.79 ± 0.01	0.82 ± 0.02	0.86 ± 0.13
Brain	0.60 ± 0.04	0.87 ± 0.03	0.64 ± 0.01	0.81 ± 0.08
Heart	0.35 ± 0.07	0.37 ± 0.02	0.35 -	0.36 ± 0.03
Femur	0.43 ± 0.01	0.48 ± 0.06	0.42 ± 0.08	0.38 ± 0.03
Spleen	0.22 ± 0.08	0.24 ± 0.02	0.28 ± 0.01	0.24 ± 0.04

[a] mean ± S.D.

TABLE 101. RELATIVE ORGAN WEIGHTS OF MALE RATS AFTER RECEIVING DIETS FORMULATED FROM GRAIN HARVESTED FROM CONTROL AND SLUDGE-AMENDED PLOTS AFTER 15 TO 20 WEEKS.

	Relative organ weight[a/] (% body)			
	Control		Sludge-fertilized	
Item	Custom	Commercial	Custom	Commercial
n	5	5	5	3
Age(da.)	146 ± 12	165 ± 7	146 ± 12	162 ± 9
Body(g)	403 ± 13	422 ± 23	393 ± 12	442 ± 34
Liver	3.52 ± 0.19	3.58 ± 0.15	3.57 ± 0.22	3.69 ± 0.02
Testicles	0.87 ± 0.03	0.87 ± 0.03	0.88 ± 0.02	0.85 ± 0.01
Kidneys	0.61 ± 0.03	0.66 ± 0.03	0.63 ± 0.03	0.67 ± 0.08
Brain	0.44 ± 0.03	0.44 ± 0.01	0.47 ± 0.03	0.42 ± 0.03
Heart	0.32 ± 0.02	0.33 ± 0.04	0.33 ± 0.01	0.32 ± 0.06
Femur	0.36 ± 0.03	0.36 ± 0.03	0.35 ± 0.02	0.37 ± 0.04
Spleen	0.18 ± 0.02	0.18 ± 0.02	0.17 ± 0.03	0.18 ± 0.02

[a/] mean ± S.D.

TABLE 102. RELATIVE ORGAN WEIGHTS OF FEMALE RATS (170-190 DAYS OLD) TERMINATED 1 TO 6 DAYS AFTER WEANING THEIR SECOND LITTER OF PUPS.

Organ	Relative organ weight[a] (% body)			
	Control		Sludge-fertilized	
	Custom	Commercial	Custom	Commercial
n	6	2	6	4
Body(g)	258 ± 23	286 ± 4	274 ± 21	266 ± 11
Liver	6.22 ± 1.22	4.70 ± 0.06	5.70 ± 0.90	4.56 ± 1.07
Ovaries	0.08 ± 0.03	0.07 -	0.08 ± 0.02	0.06 ± 0.01
Kidneys	0.80 ± 0.05	0.72 ± 0.04	0.80 ± 0.14	0.79 ± 0.11
Brain	0.63 ± 0.06	0.62 ± 0.01	0.62 ± 0.08	0.61 ± 0.05
Heart	0.50 ± 0.08	0.40 ± 0.04	0.44 ± 0.09	0.42 ± 0.07
Femur	0.39 ± 0.06	0.46 ± 0.16	0.36 ± 0.08	0.40 ± 0.04
Spleen	0.24 ± 0.03	0.20 ± 0.04	0.22 ± 0.04	0.21 ± 0.03

[a] mean ± S.D.

TABLE 103. RELATIVE ORGAN WEIGHTS OF FIRST LITTER (LIKE CROSSES) MALE RAT PUPS AT 28 DAYS OF AGE.

Organ	Relative organ weights (% body)			
	Control		Sludge-fertilized	
	Custom	Commercial	Custom	Commercial
n	24	8	13	19
Liver	5.76 ± 0.52	5.61 ± 0.31	5.66 ± 0.53	5.15 ± 0.49
Kidney	1.06 ± 0.08	1.07 ± 0.08	1.10 ± 0.08	1.08 ± 0.09
Lung	0.95 ± 0.12	1.04 ± 0.22	0.95 ± 0.12	1.01 ± 0.20
Testes	0.81 ± 0.09	0.82 ± 0.10	0.80 ± 0.08	0.83 ± 0.06
Heart	0.48 ± 0.02	0.47 ± 0.06	0.47 ± 0.06	0.48 ± 0.06
Femur	0.46 ± 0.06	0.46 ± 0.05	0.46 ± 0.05	0.51 ± 0.10
Spleen	0.40 ± 0.05	0.39 ± 0.04	0.41 ± 0.04	0.41 ± 0.05

TABLE 104. RELATIVE ORGAN WEIGHTS OF FIRST LITTER (LIKE CROSSES) FEMALE RAT PUPS AT 28 DAYS OF AGE.

	Relative organ weight (% body)			
	Control		Sludge-fertilized	
Organ	Custom	Commercial	Custom	Commercial
n	23	8	13	20
Liver	5.62 ± 0.50	5.58 ± 0.34	6.07 ± 0.87	5.11 ± 0.64
Kidney	1.02 ± 0.06	1.07 ± 0.07	1.04 ± 0.08	1.06 ± 0.09
Lung	0.98 ± 0.18	1.00 ± 0.19	0.93 ± 0.15	0.94 ± 0.14
Ovary	0.08 ± 0.03	0.07 ± 0.02	0.09 ± 0.04	0.11 ± 0.04
Heart	0.47 ± 0.04	0.52 ± 0.08	0.46 ± 0.06	0.50 ± 0.06
Femur	0.47 ± 0.05	0.45 ± 0.04	0.46 ± 0.02	-
Spleen	0.40 ± 0.05	0.38 ± 0.03	0.39 ± 0.04	0.37 ± 0.05

TABLE 105. RELATIVE ORGAN WEIGHTS OF SECOND LITTER (UNLIKE CROSSES) FEMALE RAT PUPS AT 28 DAYS OF AGE.

	Relative organ weight[a] (% body)			
	Control		Sludge-fertilized	
Organ	Custom[b]	Commercial[b]	Custom[b]	Commercial[b]
n	25	8	25	11
Liver	5.29 ± 0.38	5.14 ± 0.29	5.12 ± 0.98	4.51 ± 0.53
Kidneys	1.16 ± 0.10	1.09 ± 0.07	1.10 ± 0.24	1.07 ± 0.09
Lungs	1.08 ± 0.25	0.94 ± 0.17	1.00 ± 0.15	1.05 ± 0.23
Ovaries	0.16 ± 0.12	0.10 ± 0.03	0.12 ± 0.07	0.10 ± 0.05
Heart	0.56 ± 0.10	0.49 ± 0.13	0.54 ± 0.10	0.56 ± 0.04
Femur	0.57 ± 0.12	0.57 ± 0.13	0.57 ± 0.10	0.64 ± 0.14
Spleen	0.50 ± 0.14	0.40 ± 0.10	0.42 ± 0.09	0.38 ± 0.08

a/ Mean ± standard deviation.
b/ Diet of dam; diet of sire would be opposite (e.g. custom control x custom sludge or commercial sludge x commercial control).

two Berkshire boars that spring, farrowed in October and returned to the same plots as sows on December 2, 1976. They were again bred in January while on the plots, removed from the plots on March 15, 1977 and farrowed in the spring of 1977. The sows were terminated for examination after weaning the second litter.

Individual animals were designated by ear notches, the first number indicating the maternal parent and the second number indicating the sequence of parturition. The treatment of the plot to which they were assigned was indicated by 0, ¼, ½ or M (max) following the animal number. For example, sow 12-3-¼ was the third in a litter from Thurow Farms Sow #12 and was assigned to a ¼-maximum-sludge-treated plot; sow 12-4-0 was a sibling assigned to a control plot while sow 10-4-0 was a control plot animal from another sow.

As the gilts were introduced to the plots, they were vaccinated for Erysipalis and Leptospirosis. Penicillin/Streptomycin was administered intramuscularly for 2 days and piperazine was administered in the drinking water. Ten days after moving the gilts to the plots, several pigs developed hacking coughs. Pneumonia from the sudden change in environment was suspected and remission was noted two days after beginning Tylan therapy. Throughout the first season, several pigs required occasional re-treatment for coughing.

A standard (University of Illinois) 16% protein swine growing ration was provided ad lib, except during pregnancy and nursing. Small amounts of alfalfa hay were provided in the crates prior to farrowing, and there were no problems with postpartum constipation.

All farrowings were attended, when possible, and assistance rendered when necessary. Piglets were cleaned, cut, weighed and their needle teeth clipped at farrowing. Iron dextran injections were given at 24 to 48 hours.

The second winter was particularly severe and several sows suffered temporary lameness (from slippery conditions) and/or frostbite. Wheat straw bedding was provided throughout January during both seasons.

Complete blood cell counts, serum enzymes and electrolytes and histopathology were conducted using standard techniques. Metal concentrations were determined by atomic absorption spectroscopy after dry ashing the samples at 450°C. Samples analyzed were aliquots of whole tissues (except liver) which were frozen and homogenized with dry ice in a blender to assure homogeneous sampling. Generally 50-100 g samples of feces were prepared and analyzed by methods similar to those employed for the tissues. Cadmium binding protein was isolated from fresh tissues and evaluated by the method of Washko and Cousins (1977).

Discussion of Results

Exposure of Swine to Metals and Organics--

Sludge amended soils contained significantly higher concentrations of nutrient and non-nutrient elements and tended to have a slightly lower pH at higher application rates. Swine foraging on the maximum-sludge-treated plots tended to root less than the other treatment groups, but exposure as measured by concentrations of selected metals in fecal material and renal tissue was significantly higher at each incremental rate of sludge amendment (Table 106). Cadmium accumulated in the kidneys at a decresing percentage of the soil concentration. Chromium and Ni concentrations were quite high in the soil, but these metals did not accumulate in the kidney. Thus, these metals might be used to estimate soil ingestion. Amounts of Cu and Zn excreted in the feces were constant up to the ½-maximum-sludge-treated plots with little change in concentrations in renal tissues, indicating that this supplemental mineral source may have been absorbed and distributed throughout the animal.

Metal concentrations in fecal matter were higher in the spring than in winter, reflecting a greater amount of soil ingestion in warmer weather (Table 107). Once the sows were removed from the plots, metal contents of fecal matter declined to control levels by 5 or 6 days (Table 107). There was a surge in metal concentrations in control animal feces the day following removal from the plots. Chromium and Pb concentrations increased only in sow 11-1-0, but Cd, Cu and Zn concentrations increased in the feces of all three sows from which samples were collected. The source of contamination could not be located (if not sample contamination, perhaps the transport vehicle, the new pens or the automatic watering system). The other treatment groups did not show this surge and Cd concentrations were not elevated to values resembling the sludge treatment groups in control tissues.

There was no dose-related differences in metal concentrations in muscle, heart or lung (Table 108). There was a significant increase of Cd concentrations in the pancreas, spleen, liver and kidney. Iron concentrations in spleen, liver and kidney tended to be higher in the two intermediate groups. One explanation might be an interaction effect between increasing amounts of acid extractable iron and increasing amounts of Cd. At higher concentrations the latter element may interfere with iron absorption. Significant decreases in liver-Fe contents were observed in previous studies with corn grains from sludge-fertilized plots.

Cadmium binding protein (CBP or metallothionien) was not detectable in the kidney supernatants from control sows (Figure 115). Although the protein peak was not detectable, CBP was apparently due to the Cd peak in kidney supernatants from representative sows overwintered on ¼-max-treated plots (Figures 116 and 117). However, even though sow 10-1-M was only exposed to the plot for one season and accumulated a comparable renal Cd concentration, a small CBP peak was present showing most of the Cd had shifted from other proteins (Figures 116 and 117) to the region of CBP (Figure 118). Thus, a threshold for the effective induction of adequate CBP to sequester most of the Cd was reached somewhere between treatment groups on ½-max and maximum-sludge-treated plots.

As might be expected, the lag time between removal of the sows from experimental plots and termination after weaning their pigs was too great to preserve any CBP in the intestinal mucosa (Figure 119 and 120).

TABLE 106. METAL CONCENTRATIONS IN SOILS ANNUALLY IRRIGATED FOR 8 YEARS WITH SEWAGE SLUDGE AND IN THE FECES AND KIDNEYS OF SOWS WINTER-FORAGING ON THESE SOILS.

Treatment group	(n)	Metal Zn	Cu	Ni	Cd	Cr
		mg/kg				
Control						
Soil [a]	(4)	82	18	16.6	0.68	37.5
Feces [b]	(2)	225	22	3.6	0.59	4.4
Kidney [c]	(4)	27	5.3	<0.2	0.35	<0.5
¼-Max						
Soil	(4)	159	41	22.5	4.59	76.9
Feces	(3)	235	23	3.1	0.49	5.3
Kidney	(4)	28	3.7	<0.2	1.90	<0.5
½-Max						
Soil	(4)	265	72	27.6	9.90	129.4
Feces	(2)	228	25	3.6	0.85	8.2
Kidney	(4)	30	5.5	<0.2	3.69	<0.5
Maximum						
Soil	(4)	435	122	37.0	19.43	228.2
Feces	(4)	286	55	12.1	7.19	67.0
Kidney	(4)	31	6.4	<0.2	5.18	<0.5

[a] Spring, 1976; mg/kg dry weight.
[b] February 19, 1977; mg/kg wet weight.
[c] Summer, 1977; mg/kg wet weight.

TABLE 107. METAL CONCENTRATIONS IN THE FECES OF SOWS OVERWINTERED ON SEWAGE SLUDGE-AMENDED CORN PLOTS.

Group and time a/	(n)b/	Metal						
		Mn	Zn	Cu	Ni	Cd	Cr	Pb
		--------------------mg/kg (Fresh wt.)----------------						
Control								
0	(2)	130	225	22	3.6	0.59	4.4	5.0
1 Day	(3)	250	209	19	4.3	1.16	4.3	7.9
2	(3)	172	298	28	3.6	3.03	7.5	6.8
4	(1)	35	187	18	1.2	0.22	1.3	1.9
6	(3)	30	156	15	1.0	0.19	1.1	0.9
¼-Max								
0	(3)	69	235	23	3.1	0.49	5.3	3.1
1	(4)	-	-	-	-	1.23	-	-
4	(4)	45	174	16	1.7	0.20	1.6	1.2
½-Max								
0	(2)	96	228	25	3.6	0.85	8.2	5.8
1	(4)	176	315	36	6.0	2.33	19.7	11.4
2	(4)	90	270	27	2.4	1.65	3.9	3.4
6	(4)	30	153	15	1.2	0.20	1.4	2.0
Max								
0	(4)	176	286	55	12.1	7.19	67.0	35.4
1	(1)	253	336	64	13.0	9.01	82.2	41.7
2	(1)	94	248	30	3.1	2.37	14.0	8.1
4	(3)	42	169	18	1.6	0.67	2.0	1.0
6	(1)	38	138	13	1.2	0.23	1.4	1.1

a/ Days after removal from treated plots; day "0" was February 19; rest in March.

b/ Number of samples. Variable because pigs were removed from plots on two separate days and because adequately discreet samples were not always available.

TABLE 108. CONCENTRATIONS OF SELECTED ELEMENTS IN TISSUES FROM SOWS OVERWINTERED FOR TWO SEASONS ON SLUDGE-AMENDED SOILS (n=4).

Treatment group	Metal									
	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Cr	Pb
	--------------------------mg/kg (wet wt.)--------------------------									
						Heart				
Control	38	165	30	0.22	17	3.38	<0.18	<0.02	<0.04	0.22
¼-Max	35	176	23	0.23	16	3.57	<0.18	0.03	<0.04	<0.18
½-Max	32	149	42	0.24	17	4.00	<0.18	0.03	<0.04	0.36
Maximum	54	174	29	0.22	16	2.59	<0.18	0.03	<0.04	<0.18
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
						Lung				
Control	79	95	44	0.18	14	0.53	<0.18	0.02	0.05	0.24
¼-Max	73	83	38	0.12	13	0.57	<0.18	0.03	<0.04	0.21
½-Max	69	77	67	0.19	14	0.42	<0.18	0.08	0.04	0.35
Maximum	78	85	40	0.19	13	2.86	<0.18	0.07	<0.04	0.28
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
						Spleen				
Control	34	144	400	0.21	27	0.74	<0.18	<0.02	<0.04	0.24
¼-Max	35	152	503	0.54	28	0.67	<0.18	<0.02	<0.04	<0.18
½-Max	26	124	595	0.28	27	0.83	0.19	0.04	<0.04	0.37
Maximum	33	157	507	0.23	26	1.48	<0.18	0.10	0.04	0.23
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.05*	n.s.	n.s.
						Pancreas				
Control	78	187	20	1.15	29	0.57	0.22	<0.02	0.04	0.29
¼-Max	95	176	20	1.16	31	0.60	<0.18	0.08	<0.04	<0.18
½-Max	69	147	30	1.08	45	0.64	0.25	0.16	<0.04	0.48
Maximum	99	204	25	1.05	35	0.63	<0.18	0.28	0.06	0.25
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.17**	n.s.	n.s.
						Liver				
Control	30	133	150	1.87	57	6.15	0.19	0.03	<0.04	0.26
¼-Max	33	134	211	1.83	58	13.19	<0.18	0.33	<0.04	<0.18
½-Max	29	105	202	1.96	64	3.53	<0.18	0.43	<0.04	0.32
Maximum	37	141	158	1.57	52	5.35	<0.18	0.83	0.09	<0.18
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.52**	n.s.	n.s.
						Kidney				
Control	54	149	69	1.03	27	5.33	<0.18	0.35	0.05	0.25
¼-Max	47	144	110	1.01	28	3.70	<0.18	1.90	<0.04	0.26
½-Max	47	127	78	0.96	30	5.51	<0.18	3.69	0.04	0.28
Maximum	52	141	66	0.90	31	6.36	<0.18	5.18	0.05	0.40
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	2.88**	n.s.	n.s.

(continued)

TABLE 108. (continued)

Treatment group	Metal									
	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Cd	Cr	Pb
	------------------------mg/kg (wet wt.)------------------------									
					Muscle					
Control	31	201	14	0.09	36	0.66	<0.18	<0.02	<0.04	<0.18
¼-Max	28	200	16	0.07	36	0.66	<0.18	<0.02	<0.04	0.25
½-Max	28	176	15	0.11	37	0.59	<0.18	0.02	<0.04	0.43
Maximum	32	217	15	0.12	34	0.63	<0.18	0.03	0.06	0.28
LSD	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*,** Significantly different at $P \leq 0.05$ and $P \leq 0.01$, respectively.
n.s. Not significantly different
Less than detectable values were treated statistically by using one-half the detectable limit.

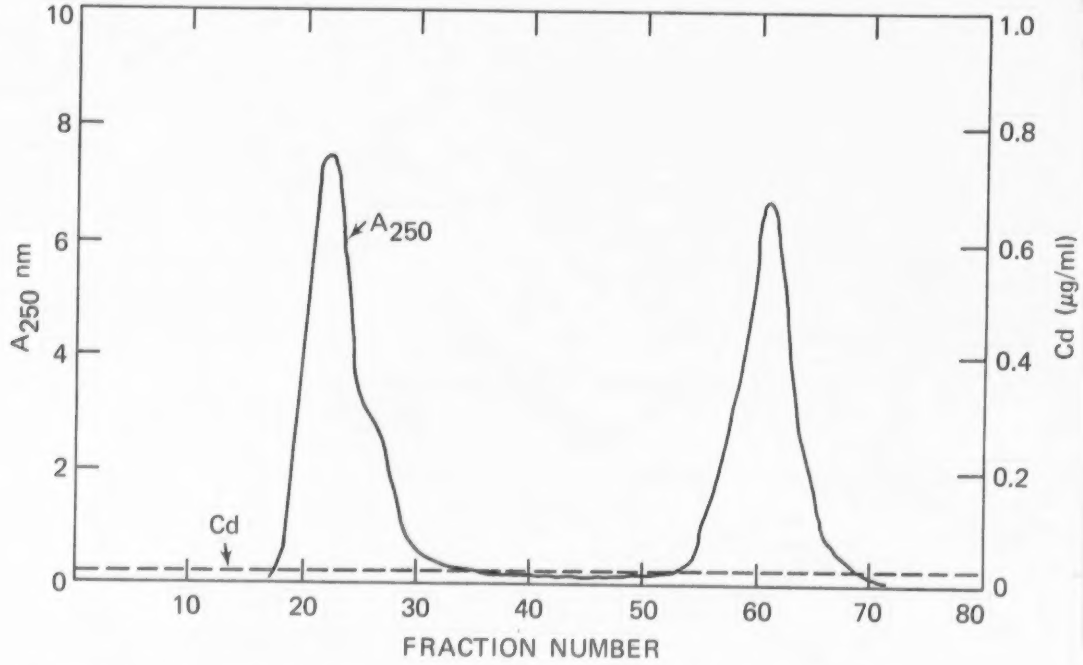

Figure 115. Lack of CBP in the renal supernatant from a representative control sow (11-1-0). Renal Cd was 0.24 mg/kg.

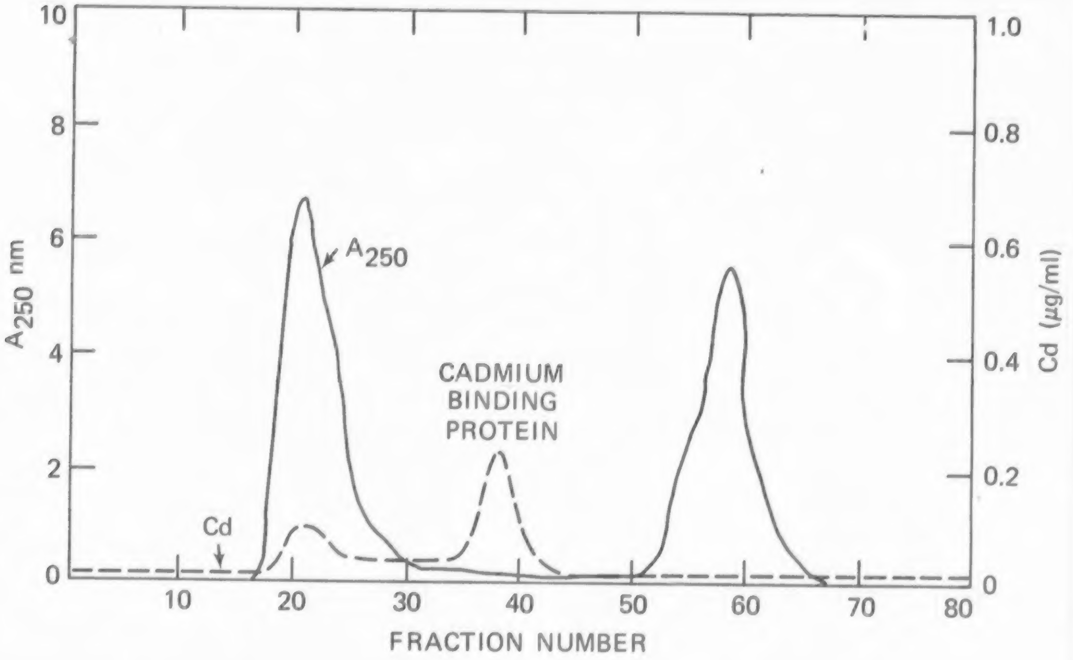

Figure 116. CBP in renal supernatant from sow 14-2-1/4. Renal Cd was 2.61 mg/kg.

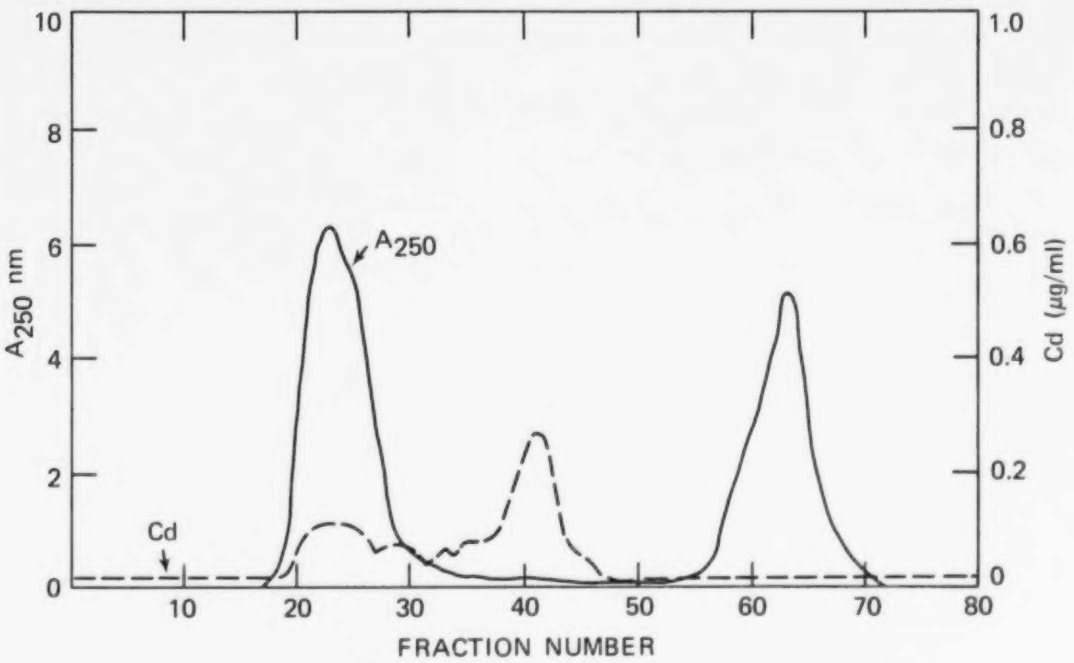

Figure 117. CBP in renal supernatant from sow 11-7-1/2. Renal Cd was 2.38 mg/kg.

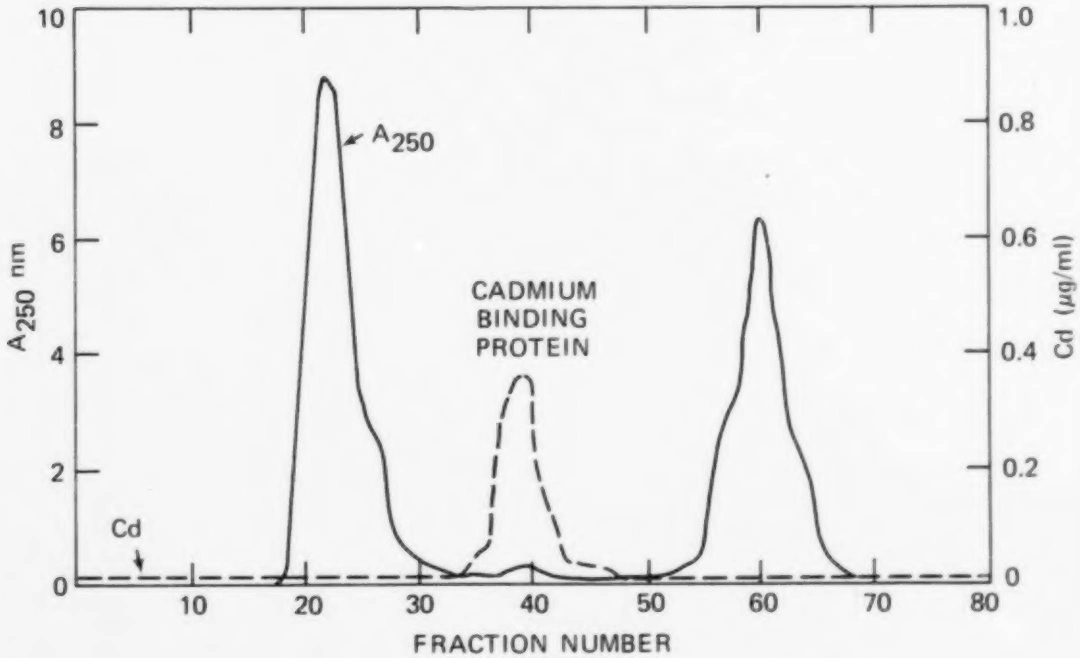

Figure 118. CBP in renal supernatant from sow 10-1-M. This sow spent only one season on the maximum treatment plot and renal Cd was 2.29 mg/kg.

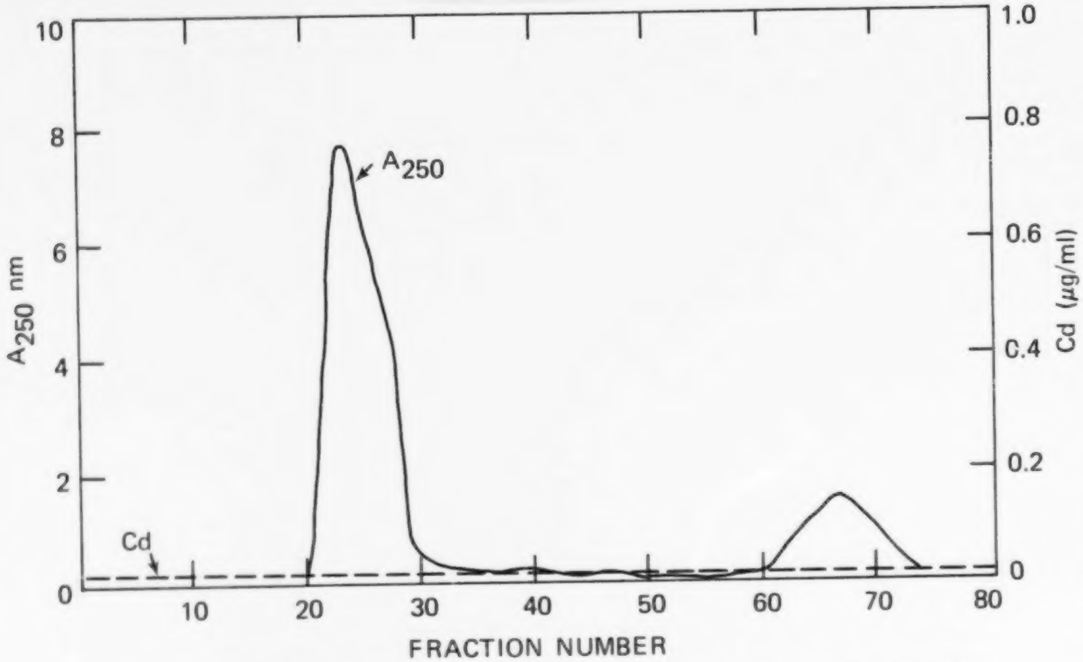

Figure 119. Cadmium and protein in the intestinal mucosa supernatant from sow 11-1-0.

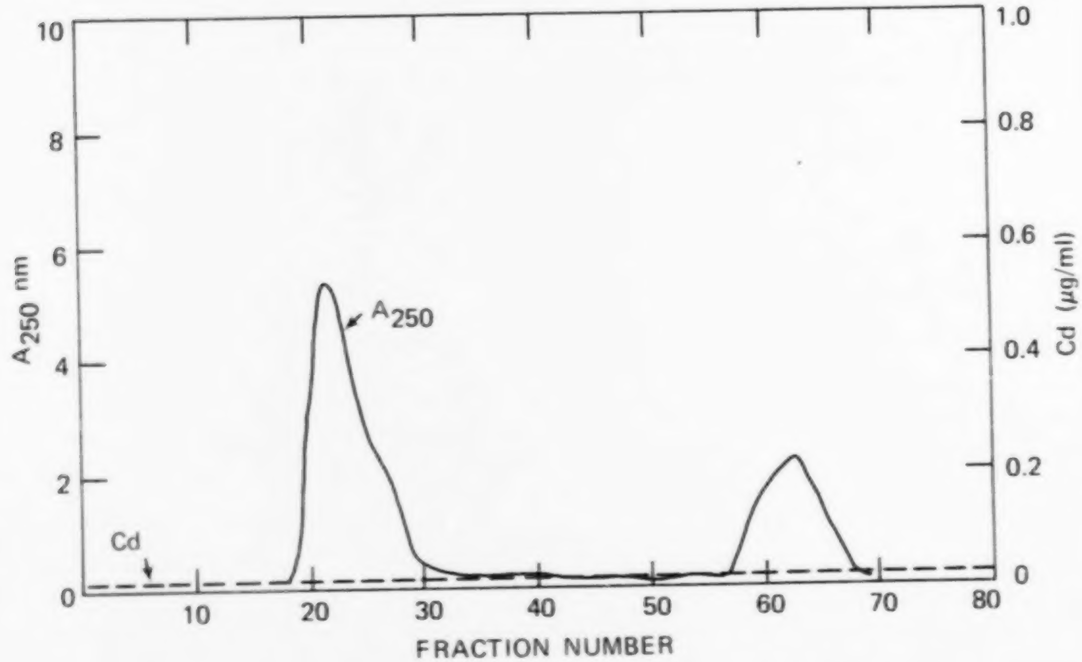

Figure 120. Cadmium and protein in the intestinal mucosa supernatant from sow 10-1-M.

Several organic residues (mainly organochlorine pesticides) have been identified in bone marrow and fat samples from the sows. In order to obtain enough material for mass spectral analysis, large amounts of the low residue fat from these sows was processed and pooled. Residues were then quantitated by comparison of a GLC series of standard pesticides or Aroclor 1254 which were run at the same time as the sample extracts. Unfortunately, phthalate esters were not anticipated and, thus could not be quantitated. Concentrations, however, are generally below 0.03 ppm, except for DDE and DDT; individual chlorobiphenyls were below 0.1 ppm.

Quantitative residue data obtained in this manner may be unreliable, so an effort is being made to re-analyze the samples. Because of other commitments, however, these data are not yet available.

Performance of Swine--

All piglets received penicillin/streptomycin soon after introduction to the plots to counteract the cough developed by several animals. Therapeutic administration of Tylan was required in addition to the prophylactic treatment for individual animals. Total (some pigs required multiple treatments) therapeutic antibiotics required by the 4 groups the first winter were: control, 5 treatments; ¼-max, 1 treatment; ½-max, 6 treatments; max, 4 treatments.

There were no treatment group differences in the initial weights of gilts or their weight at the first breeding. However, by the first weaning, the group from the maximum-sludge-treated plots had gained significantly less weight than the animals on ¼-maximum-sludge-treated plots. By the time the second litter was weaned, the sows in the ¼-maximum group were significantly heavier than all other groups. Control and ½-max groups were identical and the max group had gained the least weight (Table 109). The only littermates present in every treatment group were those from Thurow sow #12. The pattern of weight gain according to groups was ¼ > ½ > 0 > max (or very similar to the order of mean gains of ¼ > 0 > ½ > max). In fact, each sow in the group on ¼-maximum-sludge-treated plots outperformed siblings in any other group. Therefore, the differences in weight gain were more attributable to treatment group than to heredity.

Reproduction Assessment of Sows--

First litters are difficult for most swine, and the Berkshires used in this study had especially difficult times due to relatively large piglets and narrow hips. One gilt from the maximum treated plots died due to massive hemorrhages suffered during parturition. It is difficult and minimally useful to tabulate the various parturition and nursing problems, so only total piglets and fetal deaths (not full term or "NFT") are reported for the first litter (Table 110). There were no significant differences between treatment groups when the gilts were bred after overwintering on the sludge-amended plots.

TABLE 109. SUMMARIZED WEIGHT DATA FOR THE THREE MOST CONSISTENT[a] SOWS IN EACH TREATMENT GROUP.

Item	n	Sow weight (kg)			Organ weight (% body)		
		1st Wean	Farrow	2nd Wean	Liver	Kidney	Heart
Treatment group:							
Control	3	153 ± 17	199 ± 23	179 ± 11	1.28 ± 0.04	0.23 ± 0.02	0.34 ± 0.02
¼-Max	3	175 ± 9	231 ± 13	205 ± 13	1.00 ± 0.13	0.20 ± 0.02	0.30 ± 0.07
½-Max	3	156 ± 19	184 ± 13	176 ± 1	1.31 ± 0.30	0.22 ± 0.04	0.31 ± 0.04
Maximum	3	144 ± 15	178 ± 19	165 ± 20	1.23 ± 0.35	0.25 ± 0.04	0.37 ± 0.07
Littermates:							
8	2	180 ± 7	216 ± 43	198 ± 31	1.26 ± 0.32	0.24 ± 0.04	0.29 ± 0.03
10	2	154 ± 23	225 ± 1	194 ± 6	1.17 ± 0.08	0.21 ± 0.01	0.36 ± 0.04
11	2	163 ± 11	182 ± 16	172 ± 6	1.40 ± 0.11	0.24 ± 0.02	0.36 ± 0.01
12	4	148 ± 16	189 ± 26	175 ± 20	1.18 ± 0.33	0.22 ± 0.06	0.32 ± 0.07
13	1	161	196	188	0.91	0.23	0.29
14	1	135	181	157	1.18	0.23	0.40

[a] One control and one ¼-max sow did not farrow the second season; one ½-max sow did not nurse a litter the first season; one max sow spent only one season on the plots.

TABLE 110. SUMMARIZED REPRODUCTION DATA FOR ALL SOWS BY TREATMENT GROUP, SIBLING RELATIONSHIP AND 2ND LITTER FARROWING DATES.

Item	n	1st Litter		n	2nd Litter		
		Total	NFT[a]		Total	Still	NFT
Treatment group:							
Control	4	9.5 ± 1.3	0.5 ± 0.6	4[a]	8.0 ± 5.7	0.5 ± 0.6	0.8 ± 1.0
¼-Max	4	7.8 ± 3.3	0.2 ± 0.5	4[a]	5.8 ± 4.3	0.5 ± 1.0	0.8 ± 1.0
½-Max	4	8.8 ± 2.2	0	4	8.5 ± 2.9	0	0
Maximum	4	9.5 ± 2.6	0	4	10.2 ± 1.0	1.8 ± 1.0	2.5 ± 2.4
Littermates:							
8	2	9.5 ± 2.1	0.5 ± 0.7	2	11.0 ± 1.4	0	1.0 ± 1.4
9	2	8.0 ± 2.8	0.5 ± 0.7	1[a]	0	0	0
10	2	8.5 ± 3.5	0	3	9.0 ± 3.5	1.3 ± 1.5	2.0 ± 1.7
11	2	9.0 ± 1.4	0.5 ± 0.7	2	6.5 ± 2.1	0	0
12	4	8.5 ± 1.7	0	4	9.5 ± 2.4	1.2 ± 1.0	0.5
13	1	12.0	0	1	11.0	1.0	1.0
14	3	8.7 ± 4.0	0	3[a]	6.3 ± 5.5	0.3 ± 0.6	1.7 ± 2.9

(continued)

TABLE 110. (continued)

Item	n	1st Litter		n	2nd Litter		
		Total	NFT[a]		Total	Still	NFT
2nd farrowing dates:							
Apr 4-12	5	9.4 ± 1.1	0.2 ± 0.4	5	8.8 ± 2.9	0.6 ± 0.9	0.4 ± 0.9
Apr 16-21	4	9.0 ± 2.6	0	4	9.8 ± 2.1	0.8 ± 1.0	0.2 ± 0.5
May	2	11.0	0.5 ± 0.7	3	10.3 ± 0.6	1.3 ± 1.5	3.7 ± 1.5
June	2	8.5 ± 3.5	0	2	8.0 ± 4.2	0.5 ± 0.7	1.0
None	1	10	1	2	0	0	0

[a] Means include sows that did not conceive.

The second farrowing, which occurred after sows were bred on the sludge-amended plots, indicated that two-season exposure to plots which had received the maximum sludge applications resulted in more fetal deaths and stillborn piglets (Table 110). Eliminating single-litter sows, the group on maximum-sludge-treated plots performed similarly to the controls, except that there were more fetal deaths and fewer pigs were weaned (Table 111). Although seemingly fewer total conceptions occurred in sows belonging to ¼-max and ½-max groups, they would have weaned more total piglets than the extreme groups if the unrelated loss of 14 piglets from the ½-max group was considered (see footnote b, Table 111). Again, the groups on plots treated with intermediate sludge rates performed the best and the lack of fetal deaths or stillborn piglets in the ½-max group confirms the lack of a hazard at this application rate.

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Mean values from serum enzymes and electrolytes are reported in Table 112. The values are generally within the normal ranges and there are no significant differences among treatment groups.

Table 113 illustrates that sows on ½-max and max plots had slightly fewer red blood cells (RBC) shortly after they were removed from the sludge-amended soils. At this time, the sows on ¼-max plots had a significantly greater concentration of hemoglobin which may have been related to the high available iron in the soil. The stress of farrowing and nursing resulted in RBC decreases in all groups, but the decrease was more pronounced in controls. The control RBC were also the only ones which increased significantly in size (MCV of Table 113), indicating response to a minimal anemia.

The minor increases in iron stores seen in animals on sludge-treated soil at termination were probably even greater at farrowing. Thus, the sows on sludge-treated plots were better able to respond to the demands of farrowing and nursing than the controls. Of course the degree of stress would be influenced by the number of piglets nursed. These data are presented in Table 114 and further supports the supposition that the control sows were in a poorer state of iron and/or copper nutrition.

Petering (1978) believed that copper status was more important than iron for protection against lead and cadmium effects on hematopoiesis. Indeed, sludge-amended soil contained significantly greater concentrations of Cu. Although tissue levels did not vary in a dose-dependent manner, mean Cu concentrations were higher in the livers (13.2 vs. 3.5-6.2 mg/kg), spleens (1.5 vs. <0.9 mg/kg), and lungs (2.9 vs. <0.6 mg/kg) of sows on the ¼-maximum as compared to those on maximum-treated plots.

White blood cells were within a normal range for most sows (13-19 x $10^3/\mu l$) and tended to decline slightly by the time the pigs were weaned. The two sows that did not conceive had the highest white cell count within their group (67% and 22% above the group mean for 9-2-0 and 14-2-¼, respectively). Sow 11-7-½ had a large white cell population even at the time her pigs were weaned, indicating that the gross pathology seen in her litter may have been

TABLE 111. SUMMARIZED REPRODUCTION DATA FOR THE THREE MOST CONSISTENT SOWS IN EACH TREATMENT GROUPS.

Item	n	Piglet numbers				Mean piglet weights[a/]		
		Live	Still	NFT	Wean	Liveborn (kg)	Weaned (kg)	Weaned litter (kg/sow)
Treatment group:								
Control	3	10.0 ± 2.0	0.7 ± 0.6	1.0 ± 1.0	5.3 ± 3.8	1.51 ± 0.01	7.3 ± 2.5	33.1[c/] ± 22.2
¼-Max	3	7.0 ± 2.6	0.7 ± 1.2	1.0 ± 1.0	6.0 ± 1.7	1.40 ± 0.26	7.4 ± 1.6	42.6 ± 2.0
½-Max	3	8.3 ± 3.5	0	0	3.7[b/] ± 1.2	1.55 ± 0.34	8.1 ± 1.2	29.0[b/] ± 5.0
Maximum	3	8.7 ± 1.5	1.3 ± 0.6	2.0 ± 2.6	4.0 ± 3.6	1.52 ± 0.27	8.5 ± 2.2	30.3[c/] ± 21.0
Littermates:								
8	2	11.0 ± 1.4	0	1.0 ± 1.4	5.5[b/] ± 3.5	1.18 ± 0.03	6.9 ± 1.8	34.7[b/] ± 14.3
10	2	7.5 ± 3.5	0.5 ± 0.7	1.0	6.0 ± 1.4	1.60 ± 0.13	6.7 ± 2.4	38.5 ± 4.9
11	2	6.5 ± 2.1	0	0	6.5 ± 2.1	1.64 ± 0.18	6.8 ± 0.1	44.4 ± 14.1
12	4	8.2 ± 2.6	1.2 ± 1.0	0.5 ± 1.0	3.0[b/] ± 1.6	1.52 ± 0.17	9.6 ± 1.1	27.8[b/][c/] ± 13.0
13	1	10	1	1	1	1.26	8.4	8.4[c/]
14	1	9	1	5	8	1.80	6.3	50.4

(continued)

TABLE 111. (continued)

Item	n	Piglet numbers: Live	Piglet numbers: Still	Piglet numbers: NFT	Piglet numbers: Weat	Mean piglet weights[a]: Liveborn (kg)	Mean piglet weights[a]: Weaned (kg)	Mean piglet weights[a]: Weaned litter (kg/sow)
Farrowing:								
Apr 8-12	4	8.0 ± 2.9	0.2 ± 0.5	0.5 ± 1.0	4.2 ± 3.0	1.42 ± 0.18	8.6 ± 2.0	32.8[c] ± 18.2
Apr 16-21	4	9.0 ± 2.6	0.8 ± 1.0	0.2 ± 0.5	3.0[b] ± 1.6	1.37 ± 0.26	8.5 ± 0.5	25.5[b/c] ± 13.4
May	2	9.5 ± 0.7	0.5 ± 0.7	3.5 ± 2.1	8.0	1.50 ± 0.42	6.0 ± 0.5	47.6 ± 4.0
June	2	7.5 ± 3.5	0.5 ± 0.7	1.0	6.0 ± 1.4	1.60 ± 0.13	6.7 ± 2.4	38.5 ± 4.9

[a] Mean of mean litter weights for treatment groups.

[b] Includes heavy losses (9 in one litter and 5 in another) due to failure of heat lamps when piglets were 1 day old.

[c] Excluding sows which weaned only 1 pig, the means would be: Control = 44.7 ± 13.7; Max = 41.2 ± 12.9; #12 littermates = 33.7 ± 6.7; early April farrowing = 40.3 ± 12.2; late April farrowings = 31.2 ± 8.7.

TABLE 112. SUMMARY OF SERUM CHEMISTRIES OF SWINE AS UNEXPOSED WEANLINGS, AFTER ONE SEASON ON THE PLOTS, AND AT TERMINATION.

Treatment group	Parameter a/									
	CRT	T.P.	P	A.P.	CPK	SGPT	LDH	Ca	BUN	Glu
Control:										
Weanling	1.2	5.5	10.0	78	>450	61	279	12.2	11	164
1st season	0.9	6.2	7.6	56	>454	86	328	11.4	12	106
Termination	2.0	7.3	6.3	15	133	81	239	10.9	14	86
¼-Max:										
Weanling	1.2	5.5	9.9	67	181	60	244	12.2	11	132
1st season	1.2	6.3	7.7	54	242	73	308	12.0	13	114
Termination	2.3	7.2	5.3	12	46	66	202	12.1	13	88
½-Max:	1.2	5.5	9.4	71	125	59	227	11.7	11	136
1st season	1.0	6.4	8.6	60	261	78	338	11.5	14	110
Termination	2.1	7.2	6.9	20	74	81	255	10.4	12	69
Maximum:										
Weanling	1.3	5.7	10.3	74	212	66	256	12.4	10	156
1st season	0.9	6.5	8.8	55	257	87	334	12.3	15	113
Termination	2.0	7.2	6.3	15	121	70	278	11.0	12	76

a/ CRT = Creatinine (mg%); T.P. - Total protein (g%); P = phosphate (mg%); A.P. = alkaline phosphatase (Hycel International Units or HIU); CPK - Creatinine phosphokinase (HIU): SGPT = Glutamate-pyruvate transaminase (HIU); LDH = Lactate dehydrogenase (HIU); Ca = Calcium (Mg%); BUN = Blood urea nitrogen (mg%); Glu = glucose (mg%).

TABLE 113. RED BLOOD CELL CHARACTERISTICS IN SOWS AFTER REMOVAL FROM SLUDGE-FERTILIZED PLOTS (DURING GESTATION) AND AFTER WEANING THEIR SECOND LITTER.

Treatment group	RBC		Hemoglobin		PCV		MCV		MCH	
	Gest[a]	Wean[b]	Gest	Wean	Gest	Wean	Gest	Wean	Gest	Wean
Control[c]	8.32 ±0.71	6.63 ±0.89	12.5 ±0.6	11.7 ±1.8	37.8 ±2.0	36.0 ±6.2	45.6 ±3.0	54.1 ±2.5	15.0 ±1.3	17.6 ±0.7
¼-Max[c]	8.77 ±0.25	7.95 ±0.32	14.9 ±0.4	12.7 ±0.8	44.5 ±0.5	39.0 ±1.5	50.7 ±1.3	49.5 ±1.6	17.0	16.0 ±0.7
½-Max[d]	7.98 ±0.24	7.22 ±0.23	13.0 ±0.5	12.3 ±0.8	38.4 ±0.9	38.8 ±3.4	48.1 ±2.0	53.4 ±4.1	16.4 ±1.0	17.0 ±1.0
Maximum[d]	7.91 ±0.35	7.56 ±0.79	12.9 ±0.7	12.7 ±1.4	40.0 ±2.0	38.0 ±3.6	48.9 ±2.3	50.3 ±2.2	16.4 ±0.1	16.8 ±1.0

[a] Blood sample taken during gestation, 2 weeks after removal from sludge-fertilized plots.
[b] Within 3 days of weaning second litter. Duplicate samples were analyzed for each sow and averaged.
[c] n = 3 because one sow in each group did not farrow.
[d] n = 4.

TABLE 114. COMPARISON OF CHANGES IN RED BLOOD CELL NUMBERS BETWEEN GESTATION AND WEANING WITH NUMBERS OF PIGS FARROWED AND NURSED.

Sows by treatment Groups	Piglets weaned[a]	RBC	% Change[b]	Piglet PCV[c]
Control:				
12-4-0	1/12	7.40	- 2	-
10-4-0	7/10	6.83	-20	31.5 ± 2.5
11-1-0	8/8	5.66	-36	32.2 ± 3.8
¼-Max:				
12-3-¼	5/6	8.28	- 3	35.7 ± 3.2
10-6-¼	5/5	7.93	-12	36.7 ± 1.2
8-2-¼	8/10	7.63	-13	37.3 ± 0.6
½-Max:				
8-6-½	3/12	7.35	- 5	34.3 ± 1.2
12-7-½	3/8	7.37	-11	35.0 ± 2.6
11-7-½	5/5	7.30	- 8	Anemic[d]
14-8-½	7/9	6.88	-15	-
Intermediate:[e]				
10-1-M	5/8	6.66	-11	33.8 ± 1.6
Maximum:				
13-1-M	1/10	7.88	0	-
12-2-M	3/7	8.15	+ 2	34.0 ± 2.2
14-1-M	8/9	8.12	- 1	38.3 ± 0.8

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[a] Number of piglets weaned/number liveborn.

[b] Percent change in RBC (10^6 cells/μl) between sample during gestation and sample at weaning.

[c] Mean (±S.D.) packed cell volume for 3 eldest pigs at weaning.

[d] Piglets weaned from this sow were anemic (PCV=7.5 to 25%), probably due to an unidentified infectious disease in the sow.

[e] This max sow was a replacement and spent only one season on the sludge-amended soils. Cadmium residues were ½ as high as other max sows.

due to an undiagnosed microbial disease. Sow 8-6-½ had a 3.7-fold increase in neutrophils between blood samples and it is believed that this may have been a stress-induced neutrophilia when the sample was taken at weaning.

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At weaning all sows were subjected to electrical stun, exsanguination and immediate complete necropsy. Representative tissues were fixed in buffered formalin within 30 minutes of initiating the necropsy procedure. The tissues were trimmed, processed on an autotechnicon, paraffin embedded, sectioned at 6 microns, stained with hemotyxylin and eosin and examined by a veterinary pathologist. Microscopic examination did not always confirm gross observations because the lesions were patchy and fixed aliquots were not always representative of the entire tissue.

There were no significant differences in the relative weights of liver, kidney, heart (Table 109), brain, spleen, pancreas or ovaries of sows; neither were there differences in the organ weights of piglets, except for one litter (11-7-½) which seemed to be suffering from a disease condition in the sow. Hearts were smaller in individual sows with the highest hemoglobin concentrations, indicating that the elevated hemoglobin was not a transitory phenomenon.

All tissues were congested to some degree and the age of sows was reflected in various microscopic changes. There was degenerative change in all livers and mild bile duct hyperplasia in one control, one ¼-max and two ½-max sows. Patchy portal fibroplasia was seen in 11-1-0 and swollen hepatocytes in 12-4-0. Sow 14-2-¼ had extensive hepatic eosinophilic and fibroblastic activity which correlated with a slightly elevated eosinophil population in the blood and was accompanied by ascarid scars on the liver.

All kidneys had some degree of glomerular disease, and granular casts were seen in sows 14-2-¼ and 14-8-½. Increased glomerular cellularity was present in sow 12-3-¼ and two sows on maximum-treated plots. Sow 12-3-¼ also had dilated tubules as did three other sows from maximum-treated plots. Other renal lesions were limited primarily to sows in the maximum treatment group and consisted of: glomerulitis, 12-2 and 13-1; swollen glomeruli, 10-1 and 13-1; tubular degeneration, 10-1 and 14-1. Considering the low renal Cd (ca. 5 mg/kg) and the lack of any functional evidence of kidney damage, the apparent increased lesion incidence in sows overwintered on maximum-treated plots illustrates the sensitivity of the "blind" microscopic evaluation.

There was mild fatty replacement of the pancreatic parenchyma in all sows, and markedly so in two sows in each of the ¼-max and ½-max groups along with one in the max groups. Apparent focal necrosis was present in one control, two ¼-max, two ½-max and one max sow. Periductal fibroplasia was seen in the pancreas of sow 8-2-¼.

Occasionally, capsular thickening was seen in the adrenal gland and sow 10-6-¼ had mild adrenal hemorrhages.

Gross observations of the stomach revealed extensive erythema in three ¼-max sows and two max sows. Small erosions were seen in the fundus of sows 11-1-0, 12-3-¼, 14-8-½ and 13-1-M and small ulcers or areas of necrosis were present in 10-1-M and 13-1-M. Microscopic examination of small sections of the stomach, however, revealed only catarrhal exudates in 12-3-¼, three ½-max sows and sow 12-2-M so that the lesions were apparently not widespread. The sludge-laden soil was apparently somewhat irritating to the stomachs, though, and the lesions persisted or progressed for 3 to 4 months after removal from the plots.

All groups had mild eosinophilic infiltrates in the spleen. There was also a decrease in white pulp, and this was most prevalent in sows from the control group.

Sow 12-4-0 had a possible ovarian tumor while 12-7-½ had a cystic ovary. Sow 11-1-0 had duodenitis while 12-7-½ had some edema in the large intestine.

Focal spongiosis was seen in the brains of sows 8-2-¼, 10-1-max and 14-1-max. Meningeal and/or arteriolar thickening was seen in the brains of sows 9-2-0, 10-4-0 and 12-7-½, while 12-2-max and 13-1-max had increased meningeal cullularity. There was evidence for degenerative change of neurons in sow 14-8-½ and 10-1-max.

Arterioles in the myocardium were thickened in all sows in control and ¼-max groups and in one each from ½-max and max groups. Degenerative change was evident in the myocardium of sow 10-4-0, two ¼-max, all ½-max and two max sows. Sow 12-4-0 had myocardial edema, 14-2-¼, and 10-1-max had some fatty replacement and the sarcolemma nuclei were swollen in 8-6-½ and 10-1-max.

In summary, sows on the treated plots revealed increased incidence of mild gastric irritation. Mild renal disease was observed histopathologically in all sows, but this was of a greater magnitude in max sows than the renal changes seen in other treatment groups. However, none of the microscopic changes were accompanied by changes in clinical chemistry.

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APPENDIX

MAJOR PUBLICATIONS GENERATED BY THE SLUDGE UTILIZATION PROJECT

Articles

Braids, O. C., M. Sobhan-Ardakani and J. A. E. Molina, "Liquid digested sewage sludge gives field crops necessary nutrients," Illinois Research, 12 3:6-7 (1970).

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